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DAILY FLOW MODEL OF THE DELAWARE RIVER BASIN. MAIN REPORT.(U)
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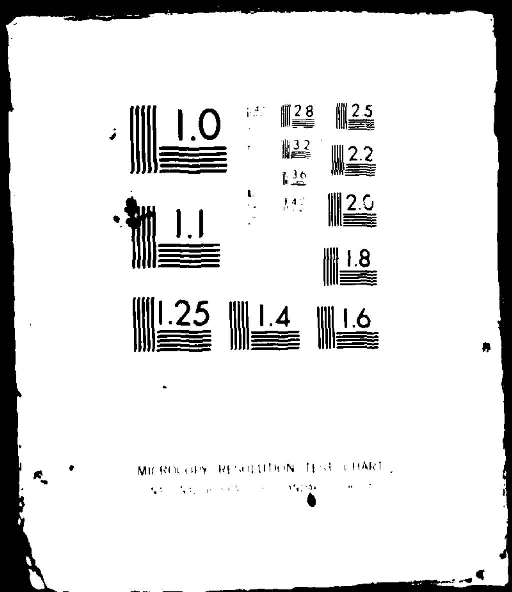

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DAILY FLOW MODEL OF THE DELAWARE RIVER BASIN

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MAIN REPORT

BOOK 1 of 2

September 1981

REPORT NO: DAEN/NAP-51850/DFM01-81/09

KEY FOR
SERIES OF DOCUMENTATION

MAIN REPORT (Book 1 of 2)

- VOLUME 1 - Phase I Report for Development of a Daily Flow Model of the Delaware River.
- VOLUME 2 - Phase II Report for Development of a Daily Flow Model of the Delaware River which Incorporates Reservoir Systems Analysis

APPENDICES (Book 2 of 2)

- APPENDIX A - Natural Daily Flows Duration and Frequency Analysis for Phase I
- APPENDIX B - Regulated Daily Flows Duration and Frequency Analysis for Phase I
- APPENDIX C - Base Run Daily Flows Duration and Frequency Analysis For Phase II
- APPENDIX D - Combination one Daily Flows Duration and Frequency Analysis for Phase II
- APPENDIX E - Combination 17 Daily Flows Duration and Frequency Analysis For Phase II

USER'S MANUAL AND DOCUMENTATION

ACKNOWLEDGEMENTS

This effort was conducted by Camp Dresser and McKee (CDM) under contract to the Philadelphia District, Corps of Engineers (PDO) with direction from a committee representing two states and four agencies. The principal engineers for CDM were Robert Taylor, Thomas George and Sue Hanson-Walton. Paul Gaudini of the Corps was responsible for the conduct of the work with technical support from Dave Erickson and Vince Hill. Members of the committee included John McSparran and Steve Runkle of the Pennsylvania Department of Environmental Resources, William Lee and Chin Liu from the New York Deoartment of Environmental Conservation, Robert Goodell of the Delaware River Basin Committee, and James Shearman from the U.S. Geological Survey. In addition, assistance was received throughout the study from George Mekenian and Raphael Hurwitz from New York City Department of Environmental Protection.

Daily Flow Model of the Delaware River Basin

US Army Corps of Engineers
Philadelphia District

September 1981

A

MAIN REPORT

PREPARED BY:

Camp Dressler & McKee, Inc.
Annondale, Va.

PREPARED FOR:

U.S. Army Corps of Engineers
Philadelphia, Pa.

IN COOPERATION WITH:

Pennsylvania Department of
Environmental Resources
Harrisburg, Pa.

New York Department of
Environmental Conservation
Albany, N.Y.

Delaware River Basin Commission
West Trenton, N.J.

U.S. Geological Survey
Harrisburg, Pa.

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This main report contains 2 volumes of the phases of work accomplished on the development of a daily flow model of the Delaware River Basin area. The first volume presents phase I of this study and contains the preliminary work of developing 50 years of historical natural inflows for selected reaches within the Delaware River Basin. It also includes an analysis of two 50 year model simulation of the flows in the entire river basin.

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The second phase of this work is described in Vol. II found in the main report. This contains an analysis which simulates the use of both existing and proposed reservoirs to maintain various flow conditions at Trenton,N.J.

ABSTRACT

Under contract to the Philadelphia Corps of Engineers, Camp Dresser & McKee developed a Daily Flow Model for the Delaware River Basin from its headwaters to the Delaware Memorial Bridge. A task committee was set up to direct the study. Members of the committee included persons from the Philadelphia District Office of the U.S. Army Corps of Engineers, the Pennsylvania Department of Environmental Resources, the New York Department of Environmental Conservation, the Delaware River Basin Commission and the United States Geological Survey. All decisions concerning model operations were a direct result of committee participation. As a preface to the work contained in this report, the assumptions and limitations of this project must be set forth. The essence of the results of this project are of a comparative basis, not to be interpreted as absolute yields of the systems analyzed as they are presently operated. The following paragraphs define the report structure and give a short synopsis of the capabilities of the Daily Flow Model.

The results of this work which were conducted in two phases, are presented in two separate volumes in this report and five appendices. The first volume presents Phase I of the work and contains the preliminary work of developing 50 years of historical natural inflows for selected reaches within the Delaware River Basin. It also includes an analysis of two 50 year model simulations of the flows in the entire river basin. One excludes all reservoirs and simply routes flows through the basin while the other includes the operation of the three New York City reservoirs, Pepacton, Cannonsville and Neversink, to maintain a low flow objective at Montaque, N.J., while at the same time allowing the diversion of water to the New York City water supply system. The results of these two simulations are presented in Appendices A and B respectively. The Appendices contain statistical low flow frequency and duration analyses at various locations within the basin.

The second phase of this work is described in Volume II of this report and contains an analysis which simulates the use of both existing and proposed reservoirs to maintain various flow conditions at Trenton, N.J. The results include a matrix of the maximum maintainable low flow values of various return frequencies which correspond to 17 different combinations of these

reservoirs. The combinations range from a single reservoir online to up to six reservoirs online to maintain the Trenton flow objectives under different hydrologic regimes. Three of the 17 combinations were also analyzed using the low-flow frequency and duration statistics as in Phase I. The results of the three simulations are presented in Appendices C, D and E.

The Daily Flow Model is capable of handling various basin operations. First and foremost the model routes flows from upstream to downstream using lag functions derived from actual maximum and minimum flow times through reaches in the watershed. Fifty (50) years of historical daily flow data were used to develop incremental inflows at 61 key locations in the basin. In order to develop the incremental inflows it was necessary to develop complete fifty year flow records at all USGS gaging stations in the basin. Incomplete or regulated records were filled-in and extended by correlation to a nearby, long-term recording station.

In addition to routing flows, the model can operate up to ten reservoirs to augment low flow conditions at two locations by establishing minimum flow targets. In this report, Montaque and Trenton, New Jersey were used as these locations. Three reservoirs in New York, Pepacton, Cannonsville and Neversink, were used to augment Montaque's flow according to the 1954 Supreme Court Decree. All other reservoirs, whether online or proposed, were used to augment the flow at Trenton.

Certain simulation procedures, particularly concerning reservoir operation, were adapted in the model that tend to cause the simulation to overestimate the real world obtainable system yields. Most of these simplifications of the real operating decisions were made in order to limit the amount of computer time required to execute the model. This constraint is a very practical concern when a model is developed to handle fifty years of daily flow data at numerous locations in such a large watershed. Perhaps, the most important model operation decision concerns the manner in which the simulation procedure makes decisions on reservoir releases. For example, when a release is needed to augment any target flow, the release is taken from the fullest reservoir using percentage as the criteria. This release scheme does not take into account hydropower optimization or water quality effects as is done be the controlling parties in the Delaware basin in the real-life situation. Other adapted procedures that

affect the simulation results are the following:

- only 50 years of exact historical hydrology are used for simulation of future conditions;
- "perfect foresight" of the next days flow conditions is used in operating the NYC reservoirs;
- reservoirs are operated with changing releases on a daily basis;
- releases are always made from the percent fullest reservoir resulting in an exactly even draw down of all facilities; and
- no considerations are made in the model of hydropower optimization, water quality conditions or existing physical limitations such as pipe capacity when releasing from reservoirs.

Even with these limitations, the model has been proven to be a powerful analysis tool for Delaware basin planners. It should be used as a comparative analysis tool, not necessarily reflecting the exact ultimate yields of the system as it is presently operated. However, the model can be made to more closely simulate with relatively minor modifications, which may have harsh affects on simulation execution times, the present operations of the system. Phase II of this report goes into much more detail concerning some of the useful applications listed below:

- analysis of bringing different reservoirs on and off line to augment low flow conditions;
- the effects of using different operations for the NYC reservoirs;
- the hydrologic possibilities and consequences of maintaining different low flow objectives at various locations; and
- determining the effects of constructing peak flow skimming facilities on the main stem or tributaries to the Delaware.

The Daily Flow Model is still relatively new and in the development phase. It has been coded for the Delaware River Basin and would require modification to be used on any other watershed. The Fortran coding is not throughly documented nor is the code itself straight forward and clean. The model was developed and used as an analysis tool to solve a particular problem and that it did exceedingly well. The purpose of this project was not the development of a generalized computer program, although with minor changes the model could fairly easily be adapted to simulate operations in other river basins where daily information has a utility. For the Delaware basin itself the model can be improved upon to make it more reflective of actual field operating conditions.

For example, the model's reservoirs can be changed to operate more closely to the real-life operations. Hydropower optimization and outlet works capacities can be included. Other special operating techniques can be added. However, these future considerations do not in any way detract from the meaningful and highly useful results given in this report.

VOLUME I

PHASE I REPORT
FOR
DEVELOPMENT OF A DAILY FLOW MODEL
OF THE DELAWARE RIVER

VOLUME I

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I. INTRODUCTION

AUTHORITY

This study is authorized by Section 22 of the Water Resources Development Act (P.L. 93-251) and Section 214 of the Rivers and Harbors Act of 1965 (P.L. 89-298). The study was requested by the Pennsylvania Department of Environmental Resources (DER) and the State of New York Department of Environmental Conservation (DEC). The Philadelphia District office of the Corps of Engineers is responsible for the conduct of the work and the study is being directed by a group consisting of staff from the Corps of Engineers, the Pennsylvania DER, the New York DEC, the Delaware River Basin Commission (DRBC), and the United States Geological Survey (USGS). The Philadelphia District Office contracted with Water Resources Engineers (WRE) an operating unit of Camp Dresser & McKee Inc. and the firm is performing work under contract number DACW61-78-C-0127.

PURPOSE

This study is being performed in two major phases. The purpose of phase one, which is documented in this report, is to investigate the flow characteristics of the Delaware River Basin under naturalized flow conditions for a 50-year base period and to determine the effects on these flow characteristics caused by the operation of the Cannonsville, Pepacton and Neversink Reservoirs. These reservoirs are a source of water supply to the City of New York and are required to be operated to meet specific flow objectives at Montague, New Jersey.

The purpose of phase two, is to determine the capabilities of various combinations of existing and proposed reservoir projects to meet maximum sustained low flow objectives at certain specified key locations.

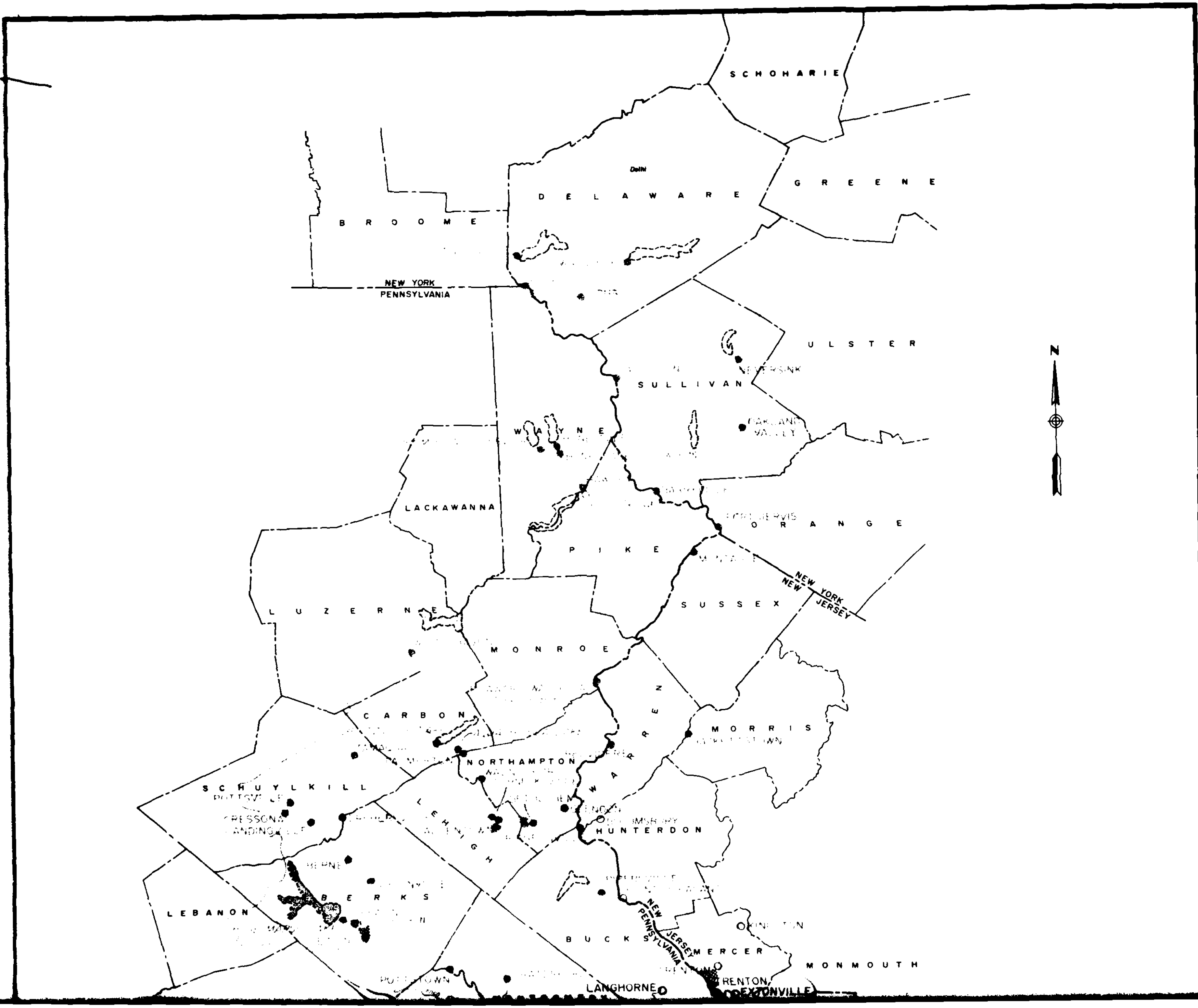
DESCRIPTION OF STUDY AREA

The study area encompasses the Delaware River Basin from its headwaters to the Delaware Memorial Bridge at Wilmington, Delaware. The basin drains parts of southern New York State, eastern Pennsylvania, western New Jersey and northern Delaware. The drainage area of the basin above Wilmington is 11,030 square miles and the basin averages about 55 miles in width and 200 miles in length. Elevations range from near 2,600 feet above mean sea level in the headwaters to 10 feet at Trenton, New Jersey. The basin is divided by the Blue-Kittatinny Mountain range which runs northeasterly through the middle of the basin. The upper basin consists of the eastern slopes of the Poconos and the western slopes of the Catskills and adjacent mountains. In the lower portion of the basin rolling hills gradually diminish to the low areas in the Atlantic Coastal Plain. Figure I-1 outlines the total Delaware River basin and shows the major tributaries and existing and proposed reservoirs. The daily flow model nodes and the key locations for duration and frequency analysis are also shown on the figure.

STUDY PROCEDURES

The major study effort involves the development of a historical daily flow simulation model of the Delaware River Basin. This model is used to produce naturalized daily flows and to analyze the effects of the operation of the three New York City reservoirs.

Natural and regulated daily flows are simulated at key locations (model nodes) for a 50-year historical period from October 1927 to September 1977. The first step in the modelling effort is to generate 50 years of natural inflows to each model node. Model nodes are put at existing USGS gages, points of proposed or existing diversion, places of proposed or existing impoundments, or other points of interest. Most model nodes are USGS stream gaging stations. Natural inflows are determined by subtracting historical USGS daily flow records of adjacent stations. When records are not available for the entire 50-year period, the daily flows of a station are generated with a correlation and extension procedure. Historical records are extended using linear regression



SCHOHARIE
GREENE
DELAWARE
Delhi
BROOME
NEW YORK
PENNSYLVANIA
ULSTER
SULLIVAN
OAKLAND VALLEY
WAYNE
LACKAWANNA
ORANGE
PIKE
NEW YORK
NEW JERSEY
SUSSEX
LUZERNE
MONROE
CARBON
MORRIS
NORTHAMPTON
WARREN
SCHUYLKILL
HUNTERDON
LEHIGH
LEBANON
BERKS
BUCKS
NEW JERSEY
PENNSYLVANIA
MERCER
MONMOUTH
TRENTON
LANGHORNE
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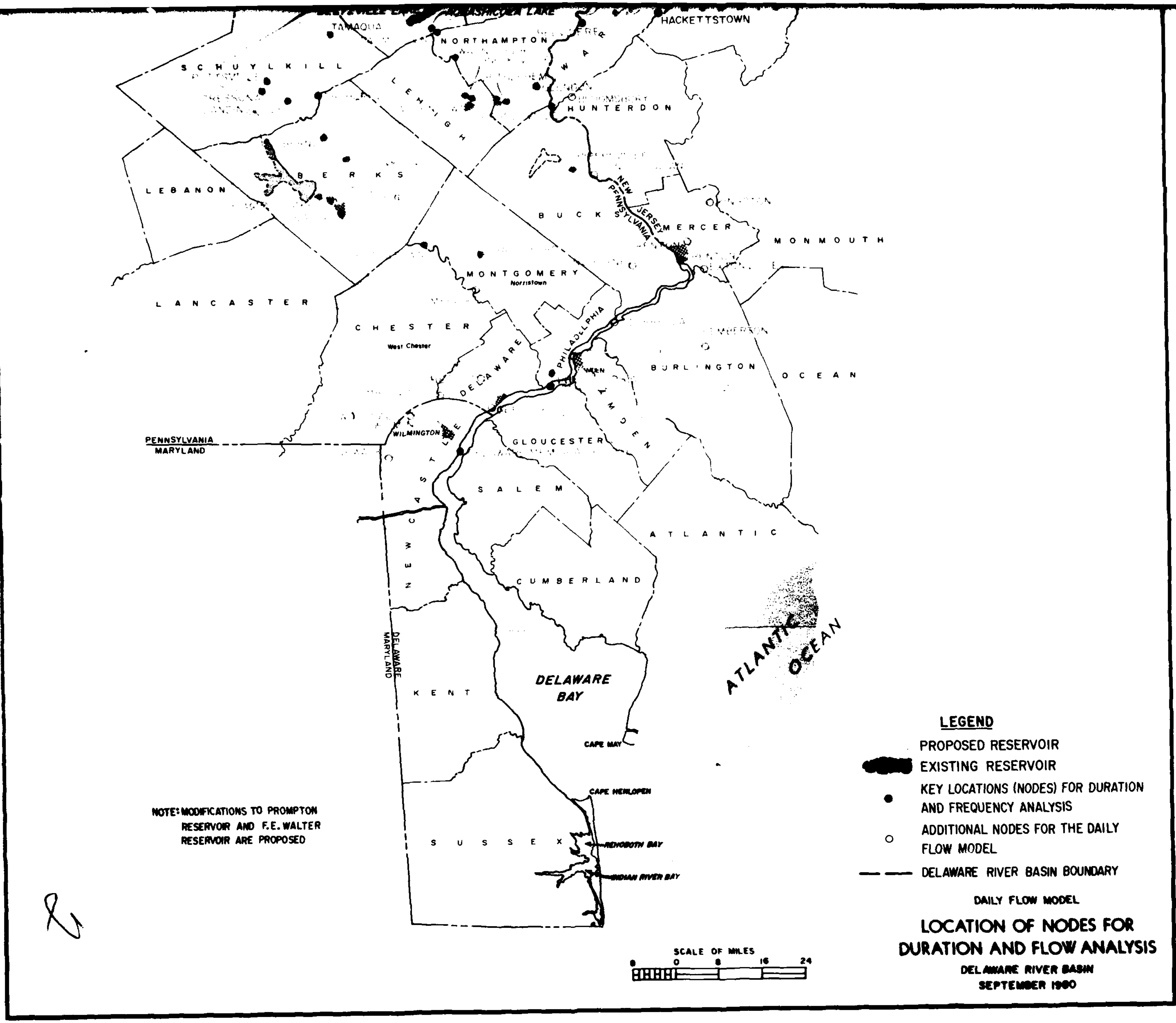

TAMAQUA
HACKETTSTOWN
NORTHAMPTON
SCHUYLKILL
LEHIGH
HUNTERDON
BERKS
LEBANON
BUCKS
NEW JERSEY
PENNSYLVANIA
MERCER
MONMOUTH
MONTGOMERY
Norristown
LANCASTER
CHESTER
West Chester
PHILADELPHIA
DELAWARE
BURLINGTON
OCEAN
CAMDEN
PENNSYLVANIA
MARYLAND
WILMINGTON
GLOUCESTER
NEW CASTLE
SALEM
ATLANTIC
CUMBERLAND
DELAWARE
MARYLAND
ATLANTIC OCEAN
DELAWARE BAY
KENT
CAPE MAY
CAPE HENLOPEN
SUSSEX
REHOBOTH BAY
INDIAN RIVER BAY
NOTE: MODIFICATIONS TO PROMPTON RESERVOIR AND F.E. WALTER RESERVOIR ARE PROPOSED
SCALE OF MILES
8 0 8 16 24
LEGEND
PROPOSED RESERVOIR
EXISTING RESERVOIR
KEY LOCATIONS (NODES) FOR DURATION AND FREQUENCY ANALYSIS
ADDITIONAL NODES FOR THE DAILY FLOW MODEL
DELAWARE RIVER BASIN BOUNDARY
DAILY FLOW MODEL
LOCATION OF NODES FOR DURATION AND FLOW ANALYSIS
DELAWARE RIVER BASIN
SEPTEMBER 1980
2

equations to long term recording stations. Natural inflows to some headwater stations are generated with a correlation and extension procedure even though records are available because the record had become regulated. The correlation, regression analysis and record extensions are discussed in Chapter II.

With the use of the naturalized inflows and travel times which are developed for various reaches throughout the basin, the simulation model produces 50 years of natural flows at 60 key locations in the basin. The daily flow model and its development is described in Chapter III. In order to analyze the natural flow characteristics in the basin, daily flow duration curves and low flow frequency curves are developed for 44 key lcoations. These results are also discussed in Chapter III, and are presented in Appendix A, Naturalized Daily Flows.

A daily regulated flow model is developed for the Delaware River Basin to determine the capability of the three New Yrok City reservoirs to meet the daily flow requirement of 1,750 cfs at Montague, New Jersey. This model uses the natural daily inflows developed for the natural flow model and the release criteria specified in the DRBC Docket D77-20[1] for the reservoirs. The analysis assumes that the reservoirs are initially full and that the reservoirs are in operation for the entire 50-year period. The New York City operating procedures, the model simulation of the reservoir systems, and the results are discussed in Chapter IV.

In order to analyze the flow characteristics of the basin simulated by the operation of the reservoirs to meet the flow objectives at Montague, duration and low flow frequency curves are developed for 18 key locations. These results are presented in Appendix B, Regulated Daily Flows.

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[1]Task Group Report DRBC Docket No. D-77-20

Appraisal of Upper Basin Reservoir Systems, Drought Emergency Criteria and Conservation Measures, Delaware River Basin Commission, March 1979.

II. NATURALIZATION OF MEAN DAILY FLOW DATA

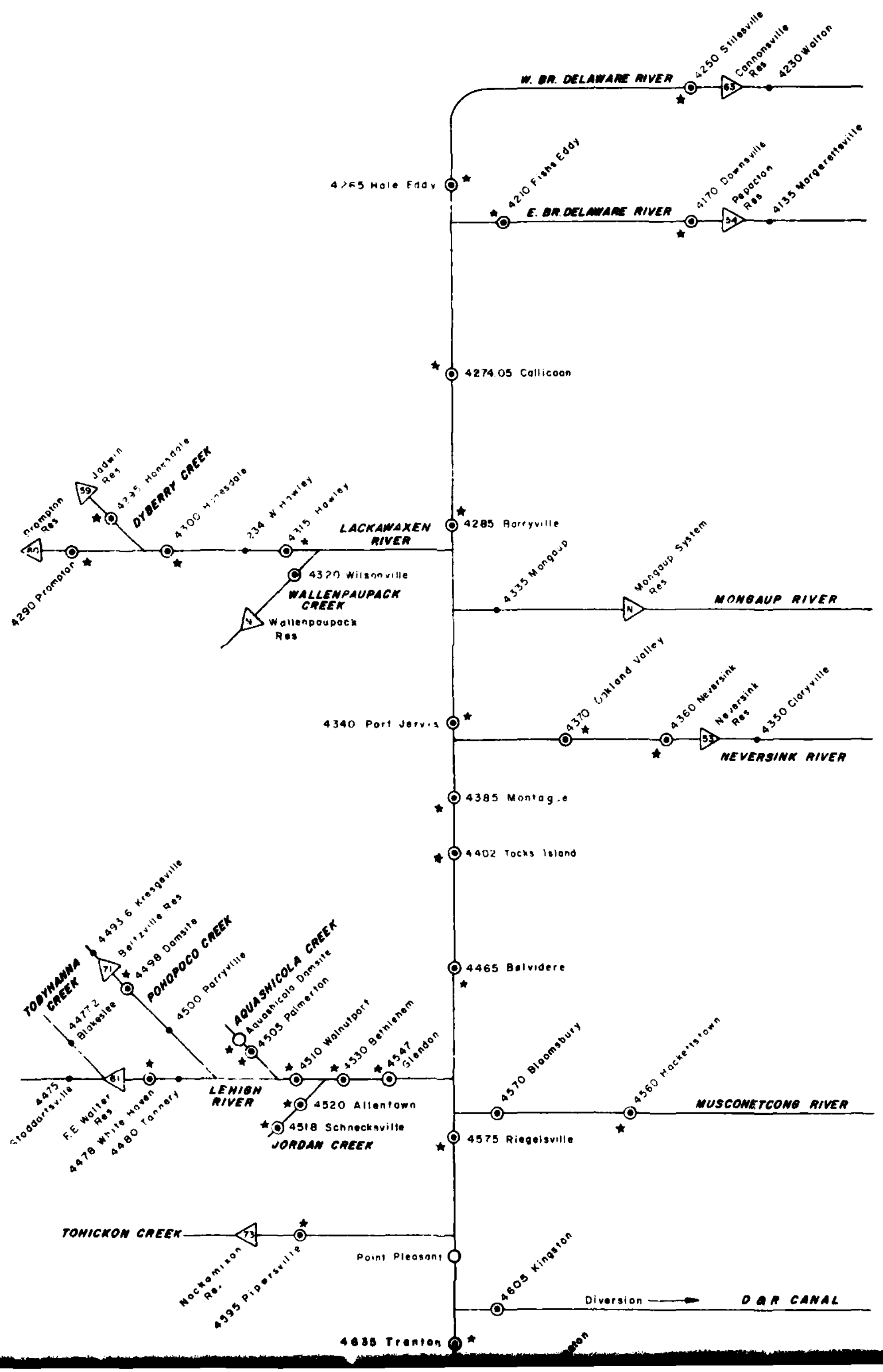
INTRODUCTION

Natural daily inflows for the Delaware River Basin above the Delaware Memorial Bridge, located at Wilmington, Delaware, are developed at key locations for a base period of 50 years. The base period, October 1927 to September 1977, covers water year 1928 through water year 1977.

Existing USGS surface water stations are used to develop the natural inflows for the base period. Some of these stations have complete records for the 50 year period; others have only partial records. Some stations are affected by regulation from upstream reservoirs for all or part of the base period of record. Therefore, the development of natural inflows for the entire base period involves an analysis of the existing records and periods during which the records are affected by regulation.

Basin Network

A schematic line diagram of the Delaware River Basin from its headwaters to the Delaware Memorial Bridge is shown in Figure II-1. This figure incorporates all the key locations for analysis required in the project. The diagram shows the location, number and name of the USGS gaging stations used in the development of the natural flows for the basin. Reservoir sites and names are also shown. The USGS gaging stations shown on Figure II-1 are listed in Table II-1 from furthermost upstream to downstream. The table includes the USGS number, location, period of record, earliest date of regulation by upstream reservoir(s) and the drainage area. The list of stations also includes locations



W. BR. DELAWARE RIVER
4250 Stilesville
Cannonsville Res
4230 Walton
4265 Hale Eddy
4210 Fishs Eddy
E. BR. DELAWARE RIVER
4170 Downsville
Pepacton Res
4135 Margaretville
4274.05 Callicoon
4285 Barryville
LACKAWAXEN RIVER
4315 Hawley
234 N Hawley
4300 Honesdale
DYBERRY CREEK
4295 Honesdale
Jadwin Res
Prompton Res
4290 Prompton
4320 Wilsonville
WALLENPAUPACK CREEK
Wallenpaupack Res
4335 Mongaup
Mongaup System Res
MONGAUP RIVER
4340 Port Jervis
4370 Oakland Valley
4360 Neversink
Neversink Res
4350 Claryville
NEVERSINK RIVER
4385 Montague
4402 Tocks Island
4465 Belvidere
TOBYHANNA CREEK
4477.2 Blakeslee
4493.6 Kresgeville
Beltzville Res
4498 Damsite
POHOPOCO CREEK
4500 Parryville
AQUASHICOLA CREEK
Aquashicola Damsite
4505 Palmerton
4510 Walnutport
4530 Bethlehem
4547 Glendon
4475 Stoddartsville
F.E. Walter Res.
4478 White Haven
4480 Tannery
LEHIGH RIVER
4520 Allentown
4518 Schnecksville
JORDAN CREEK
4570 Bloomsbury
4560 Hackettstown
MUSCONETCONG RIVER
4575 Riegelsville
TOHICKON CREEK
Nockamixon Res.
4595 Pipersville
Point Pleasant
4605 Kingston
Diversion
D & R CANAL
4635 Trenton

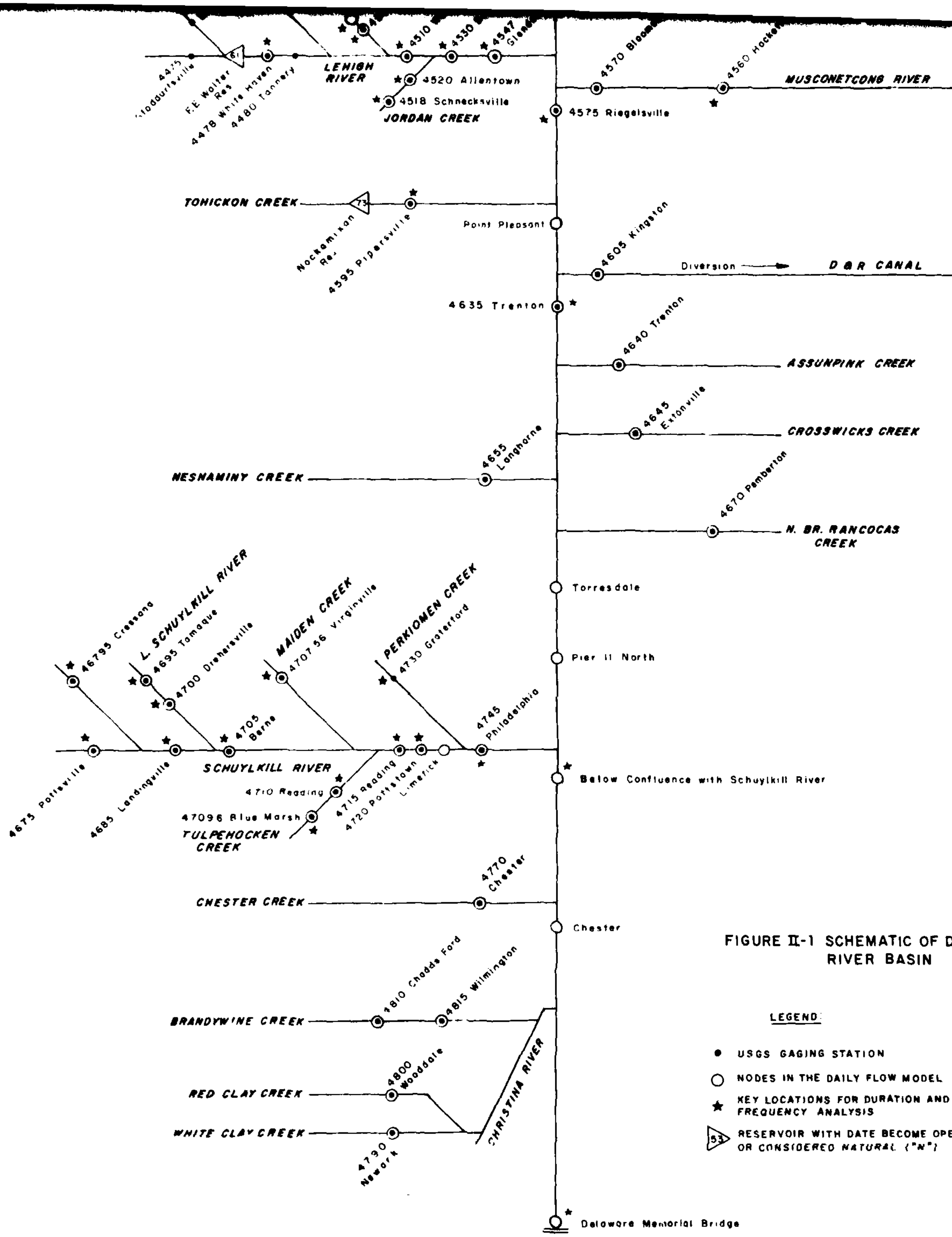


FIGURE II-1 SCHEMATIC OF DELAWARE RIVER BASIN

LEGEND:

- USGS GAGING STATION
- NODES IN THE DAILY FLOW MODEL
- KEY LOCATIONS FOR DURATION AND FREQUENCY ANALYSIS
- RESERVOIR WITH DATE BECOME OPERATIONAL OR CONSIDERED NATURAL ("N")

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TABLE II-1. USGS GAGING STATIONS

Number	Location	Period of[1] Record 1927-1977	Regulated[2] since	Drainage Area (sq mi)
01413500	E. Br. Del. R. at Margeretteville NY	4/1/[illegible]-9/30/77	-	163.0
01417000	E. Br. Del. R. at Downsville NY	10/1/41-9/30/77	Sept. 1954	371.0
01421000	E. Br. Del. R. at Fishs Eddy NY	10/1/27-9/30/77	Sept. 1954	783.0
01423000	W. Br. Del. R. at Walton NY	10/1/50-9/30/77	-	331.0
01425000	W. Br. Del. R. at Stilesville NY	10/1/52-9/30/77	Oct. 1963	456.0
01426500	W. Br. Del. R. at Hale Eddy NY	10/1/27-9/30/77	Oct. 1963	593.0
01427405	Delaware R. nr Callicoon NY	8/25/67-7/8/75	Sept. 1954	1706.0
01428500	Delaware R. nr Barryville NY	10/1/40-9/30/77	Sept. 1954	2023.0
01429000	W. Br. Lackawaxen R. at Prompton PA	10/1/44-7/26/60 8/26/60-9/30/77	July 1960	59.7
01429500	Dyberry Cr. nr Honesdale PA	10/1/43-9/30/77	Oct. 1959	64.6

TABLE II-1. USGS GAGING STATIONS (Continued)

Number	Location	Period of[1] Record 1927-1977	Regulated[2] since	Drainage Area (sq mi)
01430000	Lackawaxen R. nr Honesdale PA	10/1/48-9/30/69	Oct. 1959	164.0
01430500	Lackawaxen R. at W. Hawley PA	10/1/27-9/30/38	-	206.0
01431500	Lackawaxen R. at Hawley PA	10/1/38-9/30/77	Oct. 1959	290.0
01432000	Wallenpaupack Cr. at Wilsonville PA	10/1/27-9/30/77[3]	-	228.0
01433500	Mongaup R. nr Mongaup NY	10/1/39-9/30/77[4]	-	202.0
01434000	Delaware R. at Port Jervis NY	10/1/27-9/30/77	Sept. 1954	3076.0
01435000	Neversink R. nr Claryville NY	10/1/51-9/30/77	-	65.6
01436000	Neversink R. at Neversink NY	10/1/41-9/30/77	June 1953	91.9
01437000	Neversink R. at Oakland Valley NY	10/1/28-10/5/73	June 1953	222.0
01438500	Delaware R. at Montague NY	10/1/39-9/30/77	June 1953	3480.0

TABLE II-1. USGS GAGING STATIONS
(Continued)

Number	Location	Period of[1] Record 1927-1977	Regulated[2] since	Drainage Area (sq mi)
01440200	Delaware R. below Tocks Island Damsite	6/1/64 - 9/30/77	June 1953	3850.0
01446500	Delaware R. at Belvidere NJ	10/1/27-9/30/77	June 1953	4535.0
01447500	Lehigh R. at Stoddartsville PA	10/1/43-9/30/77	-	91.7
01447720	Tobyhanna Cr. nr Blakeslee PA	10/1/61-9/30/77	-	118.0
01447800	Lehigh R. nr White Haven PA	10/1/57-9/30/77	Feb. 1961	290.0
01448000	Lehigh R. at Tannery PA	10/1/27-9/30/59	-	322.0
01449360	Pohopoco Cr. at Kresgeville PA	10/1/66-9/30/77	-	49.9
01449800	Pohopoco Cr. below Beltzville Dam site PA	8/1/67-9/30/77	Feb. 1971	96.4
01450000	Pohopoco Cr. nr Parryville PA	10/1/40-11/12/70	-	109.0
01450500	Aquashicola Cr. at Palmerton PA	10/1/39-9/30/77	-	76.7
01451000	Lehigh R. at Walnutport PA	10/1/46-9/30/77	Feb. 1961	889.0
01451800	Jordan Cr. nr Schnecksville PA	2/1/66-9/30/77	-	53.0

TABLE II-1. USGS GAGING STATIONS
(Continued)

Number	Location	Period of[1] Record 1927-1977	Regulated[2] since	Drainage Area (sq mi)
01452000	Jordan Cr. at Allentown PA	10/1/44-9/30/77	-	75.8
01453000	Lehigh R. at Bethlehem PA	10/1/27-9/30/77	Feb. 1961	1279.0
01454700	Lehigh R. at Glendon PA	10/1/66-9/30/77	Feb. 1961	1359.0
01456000	Musconetcong R. nr Hackettstown NJ[5]	10/1/27-10/4/73	-	70.0
01457000	Musconetcong R. nr Bloomsbury NJ[5]	10/1/27-9/30/77	-	143.0
01457500	Delaware R. at Riegelsville NJ	10/1/27-10/25/71	June 1953	6328.0
01459500	Tohickon Cr. nr Pipersville PA	10/1/35-9/30/77	Dec. 1973	97.4
01460500	D and R Canal at Kingston NJ[6]	3/13/47-9/30/77	-	-
01463500	Delaware R. at Trenton NJ	10/1/27-9/30/77	June 1953	6780.0
01464000	Assunpink Cr. at Trenton NJ	10/1/27-9/30/77	-	89.4
01464500	Crosswicks Cr. at Extonville NJ	10/1/40-9/30/77	-	83.6
01465500	Nashaminy Cr. nr Langhorne PA	10/1/34-9/30/77	-	210.0

TABLE II-1. USGS GAGING STATIONS
(Continued)

Number	Location	Period of[1] Record 1927-1977	Regulated[2] since	Drainage Area (sq mi)
01467000	N. Br. Rancocas Cr. at Pemberton NJ	10/1/27-9/30/77	-	111.0
01467500	Schuylkill R. at Pottsville, PA	10/1/43-9/30/69	-	53.4
01467950	Schuylkill R. at Cressona PA	3/1/64-9/30/65	-	52.5
01468500	Schuylkill R. at Landingville, PA	8/1/47-4/30/53 10/1/63-9/30/65 8/1/63-9/30/77	-	113.0
01469500	L. Schuylkill R. at Tamaqua PA	10/1/27-9/30/77	-	42.9
01470000	L. Schuylkill R. at Drehersville, PA	10/1/47-6/30/51 10/1/63-9/30/65	-	122.0
01470500	Schuylkill R. at Berne PA	8/1/47-9/30/77	-	355.0
01470756	Maiden Cr. at Virginville, PA	1/19/73-9/30/77	-	159.0
01470960	Tulpehocken Cr. at Blue Marsh, PA	5/1/65-9/30/77	-	175.0
01471000	Tulpehocken Cr. near Reading, PA	10/1/50-9/30/77	-	211.0
01471500	Schuylkill R. near Reading, PA	10/1/27-9/30/31	-	880.0
01472000	Schuylkill R. at Pottstown, PA	10/1/27-9/30/77	-	1147.0

TABLE II-1. USGS GAGING STATIONS
(Continued)

Number	Location	Period of[1] Record 1927-1977	Regulated[2] since	Drainage Area (sq mi)
01473000	Perkiomen Cr. at Graterford PA	10/1/27-9/30/77	-	279.0
01474500	Schuylkill R. at Philadelphia PA	10/1/31-9/30/77	-	1893.0
01477000	Chester Cr. nr Chester PA	10/1/31-9/30/77	-	61.1
01479000	White Clay Cr. nr Newark DE	10/1/31-9/30/36 6/1/43-9/30/57 10/1/59-9/30/77	-	87.8
01480000	Red Clay Cr. at Wooddale DE	4/1/43-9/30/77	-	47.0
01481000	Brandywine Cr. at Chadds Ford PA	10/1/27-12/31/53 10/1/63-9/30/77	-	287.0
01481500	Brandywine Cr. at Wilmington DE	10/1/46-9/30/77	-	314.0

[1]On tape received from USGS, only includes base period from 1 October 1927 to 30 September 1977

[2]Not including Wallenpaupack Lake and Mongaup System

[3]Regulated by Wallenpaupack Reservoir since November 1925, assumed natural

[4]Regulated by Mongaup System of Reservoirs since 1927, assumed natural

[5]Regulated by Lake Hopatcong, assumed natural

[6]Diversion

needed to develop natural inflows to prospective projects on the Musconetcong, Lehigh and Schuylkill Rivers. The period of record indicated in the table only includes the base period from 1 October 1927 to 30 September 1977. The periods of record given on Table II-1 are those for which daily flow data were available from National Water Data Storage and Retrieval System (WATSTORE) of the U.S. Geological Survey, Reston, Virginia. These periods of records may vary slightly from the periods of record given in the USGS Surface Water Records publications.

The reservoirs shown on Figure II-1 are grouped into two major categories: 1) those reservoirs whose effects of regulation are to be removed from the river system for which natural inflows are developed and 2) those whose releases are considered to be a part of the natural system for the purposes of this study. For the second case the recorded flows at the immediate downstream gaging stations are used without any adjustments. The effects of the Mongaup Reservoir System and Wallenpaupack Reservoir were incorporated into the natural flow model. The reservoirs are operated for hydroelectric power, not for water supply or flood control, and are therefore assumed to be part of the natural system. Table II-2 is a list of the existing reservoirs for which natural inflows for the 50-year base period are developed. The date each reservoir became operational is also given. These dates are also shown on the line diagram of Figure II-1 and are located within the reservoir triangular symbol. Natural reservoir systems are indicated by an "N."

GENERAL PROCEDURES FOR CORRELATION AND REGRESSION ANALYSIS

To develop the natural flows at USGS gaging station sites, specific procedures for correlation and extension of flow records are carried out for several difference cases. They include:

- Extension of flows for all short term stations during the natural non-regulated period of 1 October 1927 to 2 June 1953 based on long term non-regulated stations,
- Extension of flows for all non-regulated short term stations for the remaining portion of the 50-year base period based on non-regulated long term stations,

TABLE II-2

EXISTING RESERVOIRS IN THE
DELAWARE RIVER BASIN
FOR WHICH NATURAL INFLOWS ARE DEVELOPED

Name	Location	Began Operation
Pepacton Reservoir	East Branch Delaware River	September 1954
Cannonsville Reservoir	West Branch Delaware River	October 1963
Prompton Reservoir	West Branch Lackawaxen River	July 1960
Jadwin Reservoir	Dyberry Creek	October 1959
Neversink Reservoir	Neversink River	June 1953
F.E. Walter Reservoir	Lehigh River	February 1961
Beltzville Reservoir	Pohopoco Creek	February 1971
Nockamixon Reservoir	Tohickon Creek	December 1973

- Development of natural inflows at existing reservoir sites for 50-year base period, and
- Extension of several short term regulated stations based on adjacent long term regulated stations to obtain natural incremental flow data.

This section summarizes the general procedures used for data management, correlation and extension of records for all cases. The development of natural inflows to the existing reservoirs and other special considerations are discussed in detail in subsequent sections.

Data Acquisition and Data Management

The mean daily stream flow data from 1 October 1927 through 30 September 1977 for the stations listed in Table II-1 were obtained on magnetic tape from the WATSTORE System of the USGS in Reston, Virginia. A computer program, written by WRE called FIND is used to produce an output file of daily flows which are needed as input for the correlation and regression analysis.

In general, daily flow values for a short term station whose record is to be extended are retrieved from the daily flow tape with the daily flows for nearby long term stations. The period of record retrieved for each station is identical. This permits a direct correlation of the short term station to each of the long term stations for concurrent periods of daily flow. The six major long term unregulated stations used for correlation analysis are:

- 01469500, Little Schuylkill River at Tamaqua, Pennsylvania,
- 0147200, Schuylkill River at Pottstown, Pennsylvania,
- 01743000, Perkiomen Creek at Graterford, Pennsylvania,
- 01448000, Lehigh River at Tannery, Pennsylvania,
- 01430500, (old #234), Lackawaxen River at West Hawley, Pennsylvania, and
- 01431500, Lackawaxen River at Hawley, Pennsylvania.

Other long term stations which are regulated for only part of their period of record are also used for specific cases (such as determining natural inflow at reservoir sites) where these stations are more appropriate because of the correlation period needed and the proximity of these long term stations to the stations whose flow records must be extended.

Correlation and Regression Analysis

Correlations and the determinations of linear regression equations are performed by the stepwise regression program (BMDO2R) of the Biomedical Computer Programs developed at the University of California, Los Angeles.[1] In general, the daily flow data input to the program consists of one short term station, assigned as the dependent variable, and selected long term stations, assigned as the independent variables. Prior to performing the regression analysis the program computes the means, standard deviations, and the correlation matrix. The program then computes in a stepwise manner a series of multiple linear regression equations for each independent variable added to the analysis. The first independent variable (i.e. long term stations) chosen to compute the regression equation is the one which has the highest correlation coefficient. Subsequent long term stations are added to the regression equation one at a time in order to determine if the predictability of the correlation equation can be improved. At each step the program computes, among other statistical parameters, the multiple correlation coefficient, standard error of the estimate, and the linear regression equation's constant and coefficients.

In this study the addition of more than one independent variable (long term station) to the stepwise regression analysis of daily flows did not produce a significant increase in the correlation coefficient or a significant reduction in the standard error of the estimate from those computed by using only the one long-term station which initially had the

[1] BMD, Biomedical Computer Programs, Health Sciences Computing Facility Department of Biomathematics, School of Medicine, University of California, Los Angeles, University of California Press, January 1, 1973.

best correlation. Therefore, all the equations developed to extend the short-term stations are based on the simple linear regression to one station only.

At the beginning of the project, regression analyses were performed on the actual flow data and the log transform of the flow data. In all cases, the log transform, which reduce the flow extremities to a more compact scale, produced better correlations than the actual data. Thus, in all analyses, the log transform of the data is used to develop the correlations and regression equations.

The final linear regression equation for the extension of short-term stations as produced by the BMD program's computation of the constant and coefficient is in the form:

$$LOG_{10}Y = A + BLOG_{10}X$$

where

Y = flow of short-term station,
A = constant,
B = coefficient, and
X = flow of long-term station.

This equation represents the relationship of the short-term station to a long-term station for a concurrent period of flow records. It is then used to extend or fill in missing periods of flow record for short-term stations and to develop natural flows for other stations during periods of regulation.

Flow Record Extension

The extension of flow records of the short-term stations require the manipulation of the daily flow data tape and the use of the regression equations to compute the extended flows. These procedures are done within a program written by WRE called FILLIN. The linear regression equations are used to compute the daily flows of missing periods of record for the short-term stations or the natural inflows to reservoirs. The extended

records or natural inflows to reservoirs are combined with the actual records to produce the complete 50-year base period of daily flows. Some stations are correlated to more than one station; the different correlations are used to extend different parts of the missing or regulated period of record.

Table II-3 presents a summary of the correlation and regression analyses and flow record extension in the Delaware River Basin. For each station listed the USGS number and location are given. The correlation or correlations which are finally used to extend a station's record are given. The table indicates if a station's record is not extended. Some station's records are not extended because these stations are not used as model nodes. Other station's records are not extended because the period of record of these stations exists only for a recent regulated period, making it impossible to extend the record into the unregulated period prior to 1953. For each correlated station, the table gives the correlation period, correlation coefficient, standard error of the estimate, and the constant and coefficient of the linear regression equation for the log transformation of the observed flow data. The last column of the table indicates the period of record which is extended for each station.

DEVELOPMENT OF NATURAL INFLOWS TO EXISTING RESERVOIRS

The development of the natural inflows to the existing reservoirs listed in Table II-2 are done by correlating the reservoir station to specific USGS stations for unregulated periods. The reservoir station records are extended for any missing unregulated periods, and natural inflows are developed for any regulated periods. Descriptions of the correlation and regression analysis procedures for each reservoir are given below.

Pepacton Reservoir

The Pepacton Reservoir, located on the East Branch Delaware River near Downsville, began operating in September 1954. The USGS station at Downsville (No. 01417000) is used to develop the natural inflows to the reservoir. For the 50-year base period, this station's

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01413500 E. Br. Del. R. at Margeretteville NY	(No correlation, station not extended)						
01417000 E. Br. Del. R. at Downsville NY	01421000 E. Br. Del. R. Fishs Eddy	10/1/41-8/31/54	0.9863	0.0828	-0.4737	1.0307	10/1/27-9 30 41
	01413500 E. Br. Del. R. Margeretteville	10/1/41-8/31/54	0.9852	0.0859	0.4329	0.9705	9/1/54-9/30/77
01421000 E. Br. Del. R. at Fishs Eddy NY	(No correlation, station not extended)						
01423000 W. Br. Del. R. at Walton NY	(No correlation, station not extended)						
01425000 W. Br. Del. R. at Stilesville NY	01426500 W. Br. Del. R. Hale Eddy	10/1/52-9/30/60	0.9959	0.0473	-0.0576	0.9846	10/1/27-9/30/52
	01423000 W. Br. Del. R. Walton	10/1/52-9/30/63	0.9917	0.0670	0.1881	0.9825	10/1/63-9/30/77
01426500 W. Br. Del. R. at Hale Eddy NY	(No correlation, station not extended)						

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY (continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01427405 Delaware River nr Callicoon NY	(No correlation, total period of record regulated)						
01428500 Delaware River nr Barryville NY	0142100 E. Br. Del. R.[1] Fishs Eddy and[2] 01426500 W. Br. Del. R. Hale Eddy	10/1/40-6/2/53	0.9839	0.0856	0.1911	0.9885	10/1/27-9/30/40
01429000 W. Br. Lackawaxen R. at Prompton PA	01431500 Lackawaxen R.[1] Hawley	10/1/44-6/2/53	0.9715	0.1061	-0.4462	0.9172	10/1/27-9/30/44
	01413500 E. Br. Del. R. Margeretteville	10/1/51-9/30/59	0.9160	0.1977	-0.0133	0.8168	7/1/60-9/30/77
01429500 Dyberry Cr. nr Honesdale PA	01431500 Lackawaxen R.[1] Hawley	10/1/44-6/2/53	0.9728	0.1183	-0.8219	1.0486	10/1/27-9/30/43
	01413500 E. Br. Del. R. Margeretteville	10/1/51-9/30/59	0.9197	0.2204	-0.3367	0.9337	10/1/59-9/30/77

[1]Also correlated to all other appropriate predesignated long-term stations.

[2]Flows of two stations added together.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY (continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01430000 Lackawaxen R. nr Honesdale PA	01431500 Lackawaxen R. Hawley	10/1/48-9/30/59	0.9920	0.0643	-0.1028	0.9507	10/1/27-9/30/48
	01431500 Lackawaxen R. Hawley	10/1/59-9/30/69	0.9923	0.0617	-0.2059	0.9908	10/1/69-9/30/77
01430500 Lackawaxen R. at W. Hawley PA	(No correlation, long-term station)						
01431500 Lackawaxen R. at Hawley PA	(No correlation, long-term station)						
01432000 Wallenpaupack Cr. at Wilsonville PA	(No correlation, flows assumed natural, complete period of record)						
01433500 Mongaup R. nr[3] Mongaup NY	(Not used, station not extended, total period of record regulated)						
01434000 Delaware R. at Port Jervis NY	(No correlation, complete period or record)						
01435000 Neversink R. nr Claryville NY	(No correlation, station not extended)						

[3]Correlated to appropriate predesignated long-term stations coefficients between 0.625 and 0.536. Not used.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY
(continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01436000 Neversink R. at Neversink NY	01437000 Neversink R. Oakland Valley	10/1/41-5/31/53	0.9714	0.0963	-0.1337	0.9412	10/1/27-9/30/41
	01435000 Neversink R. Claryville	10/1/51-5/31/53	0.9926	0.0498	0.2031	0.9678	6/1/53-9/30/77
01437000 Neversink R. at Oakland Valley NY	01430500 Lackawaxen R.[1] W. Hawley	10/1/28-9/30/38	0.9060	0.1705	0.6972	0.7880	10/1/27-9/30/28
01438500 Delaware R. at Montague NY	01434000 Delaware R.[1] Port Jervis	10/1/39-9/30/52	0.9955	0.0370	0.1532	0.9801	10/1/27-9/30/39
01440200 Delaware R. at Tocks Island	(No correlation, complete period of record regulated)						
01446500 Delaware R. at Belvidere NJ	(No correlation, complete period of record)						
01447500 Lehigh R. at Stoddartsville PA	(No correlation)[4]						
01447720 Tobyhanna Cr. nr Blakeslee PA	(No correlation)[4]						

[1]Also correlated to all other appropriate predesignated long-term stations.
[4]Used to determine inflow to F.E. Walter Reservoir for period 2/1/61-9/30/77 with drainage area adjustments.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY
(continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01447800 Lehigh R. nr White Haven PA	01448000 Lehigh R. Tannery	10/1/57-9/30/59	0.9946	0.0409	-0.0207	0.9924	10/1/27-9/30/57
01448000 Lehigh R. at Tannery PA	(No correlation, long-term station)						
01449360 Pohopoco Cr. at Kresgeville PA	(No correlation, station not used)						
01449800 Pohopoco Cr. below Beltzville Dam Site PA	01450000 Pohopoco Cr. Parryville	8/1/67-11/12/70	0.9776	0.0680	0.0101	0.9616	10/1/27-7/31/67
01449800 Pohopoco Cr. below Beltzville Dam Site PA	01449360 Pohopoco Cr. Kresgeville	8/1/67-1/31/71	0.9581	0.0921	0.1022	1.0378	2/1/71-9/31/77
01450000 Pohopoco Cr. nr Parryville PA	01448000 Lehigh R. at Tannery	10/1/40-9/30/59	0.9069	0.1523	-0.0929	0.8417	10/1/27-9/30/40
01450500 Aquashicola Cr. at Palmerton PA	01453000 Lehigh R.[1] at Bethlehem	10/1/48-9/30/58	0.9594	0.1108	-1.5870	1.1016	10/1/27-9/30/39

[1] Also correlated to all other appropriate predesignated long-term stations.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY
(continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01451000 Lehigh R. at Walnutport PA	1453000 Lehigh R.[1] Bethlehem	10/1/46-9/30/60	0.9854	0.0629	-0.5000	1.1092	10/1/27-9/30/46
01451800 *Jordan Cr. nr Schnecksville PA*	01472000 Schuylkill R.[1] Pottstown	2/1/66-9/30/77	0.8926	0.2305	-2.6518	1.3603	10/1/27-1/31/66
01452000 Jordan Cr. at Allentown PA	01472000 *Schuylkill* R.[1] Pottstown	10/1/46-9/30/58	0.9184	0.2069	-2.4677	1.3494	10/1/27-9/30/44
01453000 Lehigh R. at Bethlehem PA	(No correlation, *complete period of record*)						
014547000 Lehigh R. at *Glendon PA*	(No correlation, regulated for total period or record)						
01456000 Musconetcong R. nr Hackettstown NH	01451000 Musconetcong R. Bloomsbury	10/1/53-9/30/73	0.9486	0.1289	-0.7918	1.2124	10/1/73-9/30/77
01457000 Musconetcong R. nr Bloomsbury NJ	(No correlation, complete period *of record*)						
01457500 Delaware R. at Riegelsville NJ	01463500 Delaware R. Trenton	10/1/61-9/30/71	0.9917	0.0409	0.1107	0.9693	10/26/71-9/30/77

[1]Also correlated to all *other* appropriate predesignated long-term stations.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY
(continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01459500 Tohickon Cr. nr Pipersville PA	01473000 Perkiomen Cr.[1] Graterford	10/1/38-9/30/58	0.9388	0.2526	-1.4621	1.3511	10/1/27-9/30/35 12/1/73-9/30/77
01460500 D and R Canal at Kingston NJ	(No correlation, diversion)						
01463500 Delaware R. at Trenton NJ	(No correlation, complete period or record)						
01464000 Assunpink Cr. at Trenton NJ	(No correlation, complete period of record)						
01464500 Crosswicks Cr. at Extonville NJ	01467000 Rancocas Cr. at Pemberton	1/1/41-12/31/50	0.8789	0.1408	-0.2542	1.0389	10/1/27-9/30/40
01465500 Neshaminy Cr. nr Langhorne PA	01473000 Perkiomen Cr.[1] Graterford	10/1/38-9/30/58	0.9233	0.2018	-0.0422	0.9513	10/1/27-9/30/34
01467000 N. Br. Rancocas Cr. at Pemberton NJ	(No correlation, complete period of record)						
01467500 Schuylkill R. at Pottsville	01469500 L. Schuylkill R. at Tamaqua	10/1/46-12/31/65	0.9504	0.1108	0.6815	0.6962	10/1/27-9/30/43 10/1/69-9/30/77

[1] Also correlated to all other appropriate predesignated long-term stations.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY (continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01467950 Schuylkill R. at Cressona	01472000 Schuylkill R. at Pottstown	3/1/64-10/30/65	0.9507	0.1055	-0.9078	0.8652	10/1/27-2/29/64 10/1/65-9/30/77
01468500 Schuylkill R. at Landingville	01469500 L. Schuylkill R. at Tamaqua	10/1/46-12/31/65	0.9629	0.1025	0.9833	0.7522	10/1/27-7/31/47 5/1/53-9/30/63 10/1/65-7/31/73
01469500 L. Schuylkill R. at at Tamaqua	(No correlation, long-term station)						
01470000 L. Schuylkill R. at Drehersville	01469500 L. Schuylkill R. at Tamaqua	10/1/46-12/31/65	0.9720	0.0868	0.9821	0.7383	10/1/27-9/30/47 5/1/53-9/30/63 10/1/65-7/31/73
01470500 Schuylkill R. at Berne	01469500 L. Schuylkill R. at Tamaqua	10/1/46-12/31/65	0.9735	0.0936	1.2823	0.8190	10/1/27-7/31/47
01470756 Maiden Cr. at Virginville PA	01472000 Schuylkill R.[1] Pottstown	2/1/73-9/30/77	0.9359	0.1433	-1.8157	1.2483	10/1/27-1/18/73
01470960 Tulpehocken Cr. at Blue Marsh PA	01472000 Schuylkill R.[1] Pottstown	2/1/66-9/30/77	0.9469	0.1099	-0.7671	0.9645	10/1/27-4/31/65

[1]Also correlated to all other appropriate predesignated long-term stations.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY
(continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01471000 Tulpehocken Cr. nr Reading PA	01472000 Schuylkill R. Pottstown	2/1/66-9/30/77	0.9561	0.0943	-0.5279	0.9180	10/1/27-9/30/50
01471500 Schuylkill R. at Reading	01472000 Schuylkill R. Pottstown	10/1/27-9/30/30	0.9846	0.0696	-0.4608	1.1053	11/1/30-9/30/77
01472000 Schuylkill R. at Pottstown PA	(No correlation, long-term station)						
01473000 Perkiomen Cr. at Graterford PA	(No correlation, long-term station)						
01474500 Schuylkill R. at[5] Philadelphia PA	01472000 Schuylkill R. Pottstown and[2] 01473000 Perkiomen Cr. Graterford	10/1/31-9/30/56	0.9820	0.0719	0.0712	1.0084	10/1/27-9/30/31
01477000 Chester Cr. nr Chester PA	01481000 Brandywine Cr. at Chadds Ford	10/1/46-12/31/53	0.9493	0.0951	-0.5649	0.9464	10/1/27-9/30/31
01479000 White Clay Cr. nr Newark DE	01481000 Brandywine Cr. at Chadds Ford	10/1/46-12/31/53	0.9379	0.1005	-0.3123	0.8956	10/1/27-9/30/31 10/1/36-5/31/43 10/1/57-9/30/59

[2] Flows of two stations added together.
[5] City of Philadelphia municipal water supply diversion flows added to gaged flows.

TABLE II-3. CORRELATION AND FLOW RECORD EXTENSION SUMMARY
(continued)

Station Number & Location	Correlated to Number & Location	Correlation Period	Correlation Coefficient (Logs)	Standard Error (Logs)	Equation Constants LogY = A + B(LogX) A	B	Period Extended
01480000 Red Clay Cr. at Wooddale DE	01481000 Brandywine Cr. at Chadds Ford	10/1/46-12/31/53	0.9058	0.1270	-0.5464	0.8948	10/1/27-3/31/43
01481500 Brandywine Cr. at Willmington DE	01481000 Brandywine Cr. at Chadds Ford	10/1/46-12/31/53	0.9913	0.0397	0.0910	0.9860	10/1/27-9/30/46

period of record is from October 1941 to September 1977. For the nonregulated period from 1927 to 1941, the Downsville records are extended by correlation of the Downsville station to the station at Fishs Eddy (No. 01421000) on the East Branch Delaware River. Natural inflows for the regulated period of record from 1954 to 1977 are created by correlation of the Downsville station to the station at Margeretteville (No. 01413500), which is located above the reservoir on the East Branch Delaware River.

Cannonsville Reservoir

The Cannonsville Reservoir, which began operation in October 1963 is located on the West Branch Delaware River near Stilesville. The USGS station at Stilesville (No. 01425000) is used to develop the natural inflows to the reservoir. Its period of record is from October 1952 to September 1977. For the non-regulated period from 1927 to 1952, the Stilesville records are extended by correlation to the Hale Eddy Station (No. 01426500), located downstream on the West Branch Delaware River. Natural inflows for the regulated period of record at Stilesville are determined by correlation to the station at Walton (No. 01423000), located above the reservoir on the West Branch.

Prompton Reservoir

The Prompton Reservoir, which is located on the West Branch Lackawaxen River, became operational in July 1960. The USGS station at Prompton (No. 01429000) is used to develop the natural inflows. The period of record for this station is from October 1940 to September 1977. All long-term stations are used to find the best correlation with Prompton. The downstream station at Hawley (No. 01431500) is selected to extend the non-regulated period of record from 1927 to 1940 because it has the best correlation. There does not exist a gaging station above Prompton Reservoir which could be used to develop the natural inflows to the reservoir during the regulated period by correlation with the Prompton station, as is done for Pepacton and Cannonsville Reservoirs. Non-regulated stations in the upper portion of the basin are chosen for correlation analysis. The station at Margeretteville (No. 014135000) is selected for correlation and is used to extend the flow record at the Prompton site during the regulated period of record.

The extended flows at Prompton based on Margeretteville are compared for verification to the mean daily inflows of the Monthly Reservoir Operation reports prepared by the Philadelphia District office of the Corps of Engineers. The reports give the daily inflow, outflow, and pool elevation. Records are available from October 1965 with some missing periods. Non-regulated flows at Prompton based on Margeretteville compare favorably, with some scatter, to the inflows of the operation reports. Therefore, the method of correlation and extension with Margeretteville is considered to produce an adequate representation of the natural inflow to the reservoir.

Jadwin Reservoir

Jadwin Reservoir, which became operational in October 1959, is located on Dyberry Creek, a tributary to the Lackawaxen River. The USGS station located on Dyberry Creek near Honesdale (No. 01429500) is used to develop the natural inflows to the reservoir. Its period of record is from October 1943 to September 1977. Flow records are extended by correlation to the Lackawaxen River Station at Hawley (No. 01431500) for the non-regulated period and by correlation to Margeretteville (No. 01413500) for the determination of the natural inflows to Jadwin during the regulated period of record.

Neversink Reservoir

Neversink Reservoir, which is located on Neversink River, became operational in June 1953. The USGS station at Neversink (No. 01436000) is used to develop the natural inflows to the reservoir. The period or record during the 50-year base period is from October 1941 to September 1977. The Neversink flow record is extended by correlation to the Oakland Valley Station (No. 01437000) on the Neversink River for the non-regulated period from 1927 to 1941. The creation of the natural inflows to the reservoir during the regulated period of the Neversink station from 1953 to 1977, is done by correlation to the Claryville Station (No. 01435000) which is located above the Neversink Reservoir.

F. E. Walter Reservoir

F. E. Walter Reservoir, which became operational in February 1961, is located on the Lehigh River near White Haven. The USGS station near White Haven (No. 014478000) is used to develop the natural inflows to the reservoir during the non-regulated period. Its period of record is from October 1957 to September 1977. The White Haven flow record is extended by correlation to the station on the Lehigh River at Tannery (No. 01448000) for the period from 1927 to 1957. The natural inflows to the reservoir from 1961 to 1977 are developed by prorating the sum of the flows at two upstream stations, Stoddartsville on the Lehigh River and Blakeslee on Tobyhanna Creek, to the damsite by a drainage area proportion ratio.

The natural inflow of the reservoir based on a drainage area ratio and the two upstream stations are compared to the mean daily inflows of the Monthly Reservoir Operation reports prepared by the Philadelphia District office of the Corps of Engineers. Records are available from February 1973 through September 1977 with some missing periods. The flows developed from the two upstream stations compare very well to the flows of the operation reports and this method is used to determine the natural inflows to the reservoir during the regulated period of the White Haven station.

Beltzville Lake

Beltzville Lake, which is located on Pohopoco Creek, a tributary to the Lehigh River, became operational in February 1971. The USGS station on Pohopoco Creek below Beltzville dam site (No. 01449800) is used to develop the natural inflows to the lake. The period of record at this station is from 1967 to 1977 for the 50-year base period. For the non-regulated period, the flow record at the Dam Site is extended, based on correlation to the station at Parryville (No. 01450000) whose records are extended based on correlation to the Lehigh River station at Tannery (No. 01448000). The creation of the natural inflows to the lake at the Dam Site for the regulated period of record is based on the correlation of the Dam Site station to the station at Kresgeville (No. 01449360) which is located upstream of the reservoir and has a period of record from 1966 to 1977.

The extended flows at the Dam Site based on Kresgeville are compared for verification to the mean daily inflows of the Monthly Reservoir Operation reports prepared by the Philadelphia District Office of the Corps of Engineers. Records are available from February 1973 through September 1977 with some missing periods. The natural inflow at the Dam Site based on correlation with Kresgeville, compare favorably to the inflows of the operation reports. Therefore, the method of correlation and extension with Kresgeville is considered to produce an adequate representation of the natural inflow to the Lake for the regulated period of the Dam Site station.

Nockamixon Reservoir

The Nockamixon Reservoir, which became operational in December 1973, is located on Tohickon Creek near Pipersville. Natural flows are developed at the USGS station at Pipersville, whose period of record is from October 1935 to September 1977. The non-regulated period of record at Pipersville is correlated to the long-term stations. The long-term station which produces the best correlation is at Graterford on Perkiomen Creek (No. 01473000). This station is used to extend the flow record of Pipersville from 1927 to 1935 for the non-regulated period and also from 1973 to 1977 for the regulated period of the Pipersville station.

SPECIAL CONSIDERATIONS

In addition to the general procedures described for correlation, regression analysis, extension of flow records, and the development of the natural inflows to the existing reservoirs, special considerations are required for the development of natural flows at the Philadelphia station on the Schuylkill River and for the Delaware and Raritan Canal diversions.

Schuylkill River Station at Philadelphia

The recorded daily flows at Philadelphia do not include the diversions above the station by the City of Philadelphia for municipal water supply. The diversion flow is accounted for in order to produce the natural flow at the Philadelphia station for its period of record from October 1931 to September 1977, and to correlate the gaged flows plus the diversion flows to a long-term station in order to extend the flow record from 1927 to 1931.

Pumping records were obtained from the City of Philadelphia for the Belmont, Queen Lane, and Shawmont Schuylkill River stations. These records and the gaging station records are used to create the natural flow of the Schuylkill River at Philadelphia from 1931 to 1977. The extension of the natural flow record from 1927 to 1931 is accomplished by correlating the Philadelphia station flows plus the diversion flows to the sum of the flows recorded at the Pottstown station on the Schuylkill River (No. 01472000) and the Graterford station on Perkiomen Creek (No. 01473000).

Delaware and Raritan Canal

The Delaware and Raritan (D&R) Canal diverts water from the Delaware River at Raven Rock, which is located north of Trenton, New Jersey. Flow records are available beginning March 1947 to the present from the USGS gaging station located at Kingston, New Jersey.

In order to determine the diversion flow prior to 1947 the New Jersey Bureau of Water Facility Operations, were contacted for assistance. No flow records for this period are available, and the canal went through several operational and rehabilitation changes throughout this period. The canal, which was originally open for navigation in 1834, was closed to navigation in 1933 by the railroad company which owned the canal at that time. In 1934, the State of New

Jersey became the new owner, and for the next ten years, studied the possible uses of the canal. In 1944, the D&R Canal was rehabilitated for use as an industrial water supply, and in 1949 it was rehabilitated for potable water supply.

An estimate of the canal diversions before the establishment of the gage at Kingston was based on an interview with operational personnel. For the ungaged period from 1927 to 1947, the daily diversion flow for the D&R Canal is estimated to be 50 cfs.

CORRELATION ACCURACY CHECK

Additional checks on the correlation results are conducted for eight selected stations. They include:

- 01417000, East Branch Delaware River at Downsville, NY,
- 01425000, West Branch Delaware River at Stilesville, NY,
- 01428500, Delaware River near Barryville, NY,
- 01436000, Neversink River at Neversink, NY,
- 01437000, Neversink River at Oakland Valley, NY,
- 01438500, Delaware River at Montague, NY,
- 01451000, Lehigh River at Walnutport, PA, and
- 01474500, Schuylkill River at Philadelphia, PA.

Concurrent years of flow for these stations and the stations used in the correlation analysis are used with the correlation equations, presented in Table II-3, to re-generate the actual flows for the eight stations. The Downsville and Stilesville gages actually use two correlation equations to complete the record. However, for the correlation check only the equations developed by using Fishs Eddy for Downsville and Hale Eddy for Stilesville are used.

The accuracy of the re-generated flows are analyzed by correlating the re-generated flows to the actual flows using the regression program BMD02R discussed and referenced in the section Correlation and Regression Analysis. The results of the correlation of observed and computed flows for the eight stations are presented in Table II-4. The table gives the station number and location, the correlation coefficient, the observed and computed mean discharge for the concurrent years of flow used, and the constants A and B for the linear regression equations. The equation is in the form:

$$Y = A + B(X)$$

where Y = Observed flow (cfs),
X = Computed flow (cfs) and
A,B = constants

Six of the eight stations have correlation coefficients greater than 0.95. Lower correlation coefficients are calculated for the Neversink River, 0.93 at Neversink and 0.87 at Oakland Valley. The differences in the observed and computed mean discharges for the period of record analyzed are less than two percent for all stations except the two on the Neversink River. For the station at Neversink the computed mean is 6 percent low and for the station at Oakland Valley the computed mean is 16 percent high.

The equations presented in Table II-4 demonstrate how well the re-generated (or computed) flows compare to the observed flows. If the computed flows were re-generated to be equal to the observed flows for each and every day of the period of record analyzed the constant A would equal zero and the constant B would equal one. Graphically, this perfect fit would produce a line with the y-intercept at zero and a slope of one (45^{o} angle) when the observed versus computed values are plotted. Figures II-2 through II-9 present plots of the regression equation developed for the concurrent years of discharges for the eight stations. In each figure the observed is given on the ordinate and the computed is given on the abscissa. The regression equation is plotted with triangular symbols to a point approximately equal to twice the mean flow. The figures also include a straight line at a 45^{o} angle without a symbol to represent a perfect fit. These figures demonstrate that the correlation equations used to fill-in missing or regulated periods of record are highly accurate with the exceptions of the Neversink River at Neversink, Figure II-5, the Neversink River at Oakland Valley, Figure II-6, and the Lehigh River at Walnutport, Figure II-8.

The Neversink River at Neversink extended flows are based on the Neversink River gage at Oakland Valley as shown in Table II-3. For the concurrent period of record analyzed, the re-generated flows for Neversink from Oakland Valley show that the filled-in flows are over estimated for discharges less than 150 cfs and are underestimated for discharges greater than 150 cfs. Therefore, during low flow periods of the actual extended

period from October 1927 through September 1941 the flows at Neversink are slightly overestimated. For example the 7Q10 for Neversink based on the 50 years of naturalized flows, which includes filled-in and recorded flows, is 15 cfs. The 7Q10 at Neversink based on the regression equation of Table II-3 and the 7Q10 at Oakland Valley is 20 cfs.

The Neversink River gage at Oakland Valley is extended for one year only (water year 1928) and is based on the flows at West Hawley on the Lackawaxen River. Figure II-6 shows that for the concurrent period of record analyzed the re-generated flows are always overestimated. Thus, the filled-in flows for the water year 1928 are probably greater than those that actually occurred for that one year.

The Lehigh River at Walnutport extended flows are based on the Lehigh River flows at Bethlehem as shown in Table II-3. For the concurrent period of record analyzed the re-generated flows are underestimated for discharges less than 1700 cfs and are over estimated for discharges greater than 1700 cfs as shown in Figure II-8. This relationship is produced for the concurrent period of record from water year 1953 through water year 1960. However, analyzing the 50-year of naturalized flows the 7Q10 for Walnutport is 205 cfs, and the 7Q10 at Walnutport based on the 7Q10 at Bethlehem and the regression equation of Table II-3 is 222 cfs which is an eight percent increase. Therefore, in this case, the analysis of the concurrent period of record may not be indicative of the relationship produced by the regression equation developed from the correlation of Walnutport to Bethlehem. Thus the regression equation is maintained to predict the missing period of record for Walnutport.

In general the correlation analysis and fill-in procedures are adequate to produce 50 years of daily naturalized flows for modeling of the Delaware River basin. The total flows developed for these stations and the other stations in the basin are used to produce incremental inflows by lagging and subtracting the filled-in flow records of adjacent stations as described in the following Chapter.

TABLE II-4

CORRELATION OF OBSERVED
AND COMPUTED (RE-GENERATED) FLOWS

Station Number & Location	Correlation Coefficient	Mean Discharge[1] (cfs) Observed	Computed	Equations Constants[2] Y = A + B(X) A	B
01417000 E. Br. Del. R. at Downsville NY	0.979	698	693	24	0.972
01425000 W. Br. Del. R. at Stilesville NY	0.996	811	796	-4	1.024
01428500 Delaware River nr Barryville NY	0.972	3783	3721	48	1.004
01436000 Neversink R. at Neversink NY	0.933	246	232	-27	1.179
01437000 Neversink R. at Oakland Valley NY	0.870	434	503	-37	0.936
01438500 Delaware R. at Montague NY	0.997	6451	6472	117	0.979
01451000 Lehigh R. at Walnutport PA	0.987	1738	1748	224	0.867
01451000 Schuylkill R. at Philadelphia PA	0.973	2924	2910	33	0.993

[1]mean discharge for correlation period

[2]y = observed flow, X = computed flow

DOWNSVILLE, N.Y.

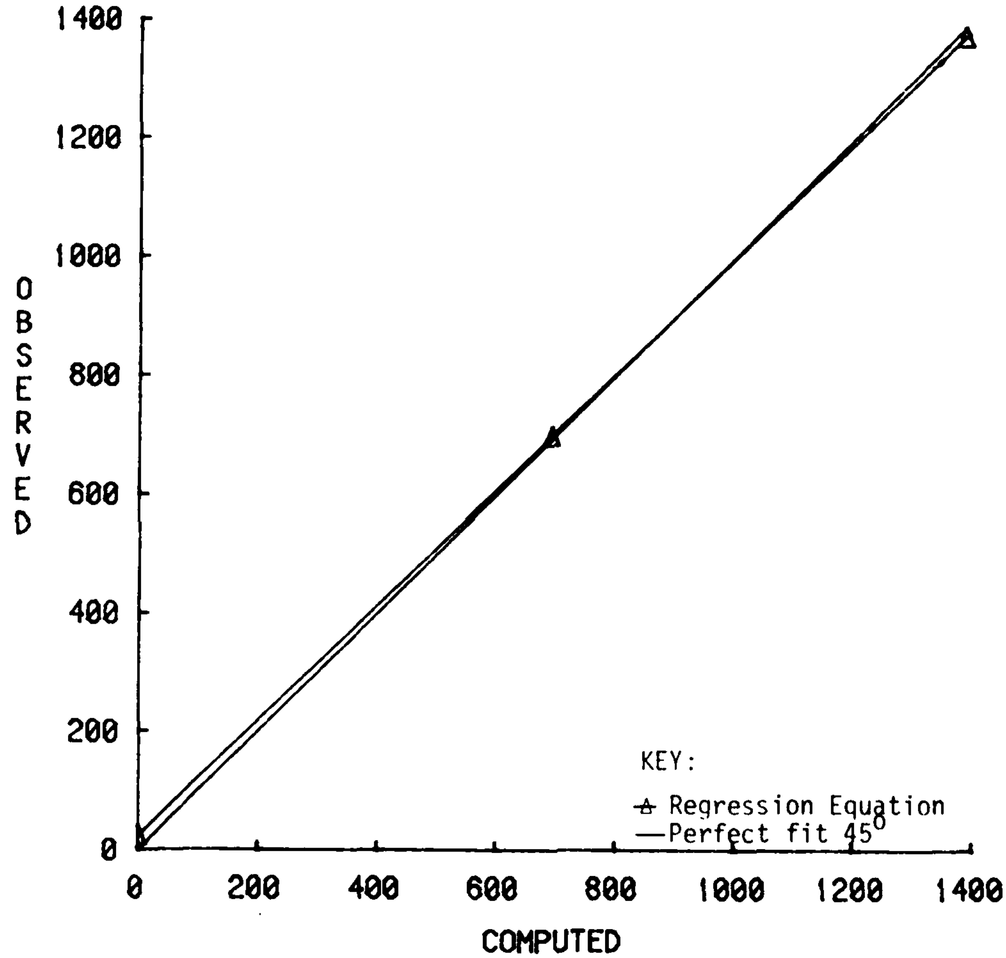

FIGURE II-2. Correlation Accuracy Check: 01417000
East Branch Delaware River at Downsville, NY

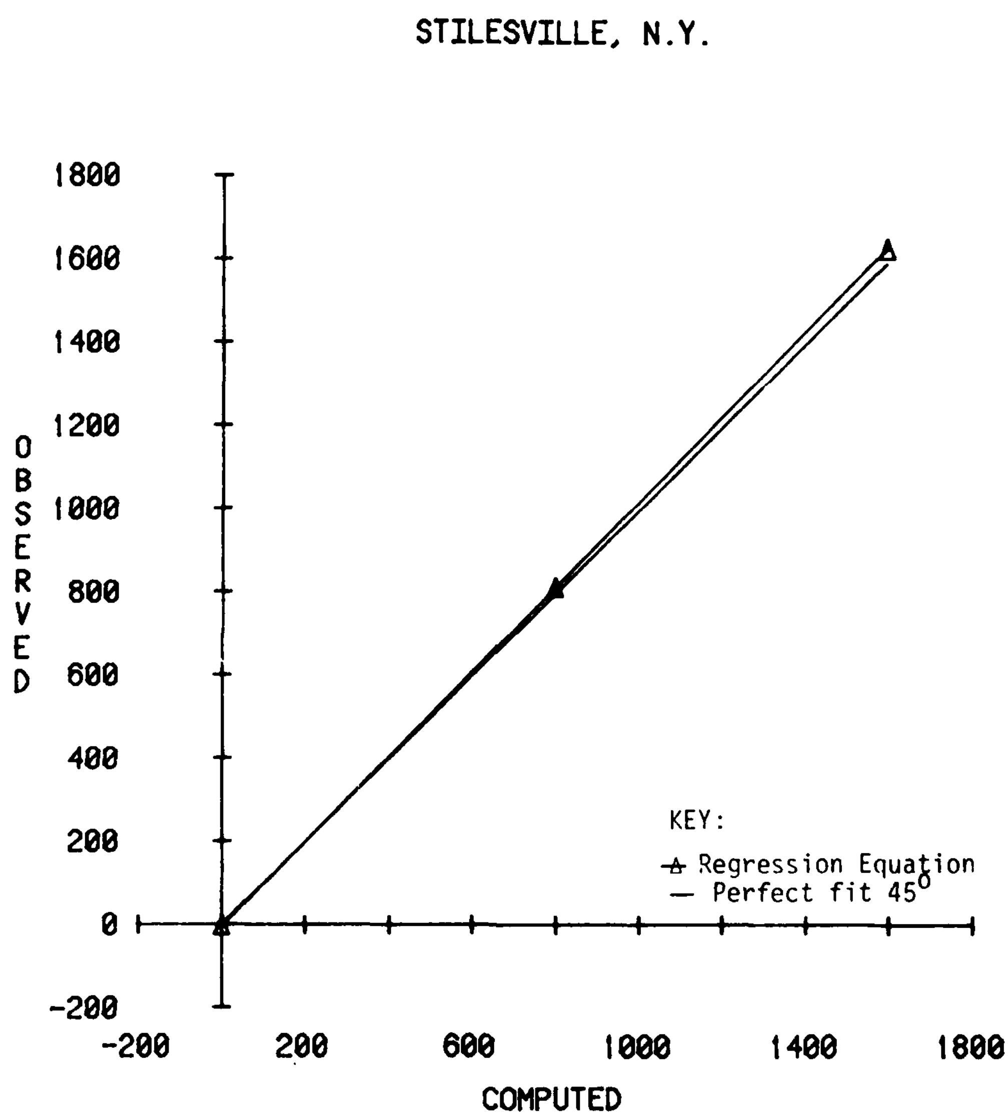

FIGURE II-3. Correlation Accuracy Check: 01425000
West Branch Delaware River at Stilesville, NY

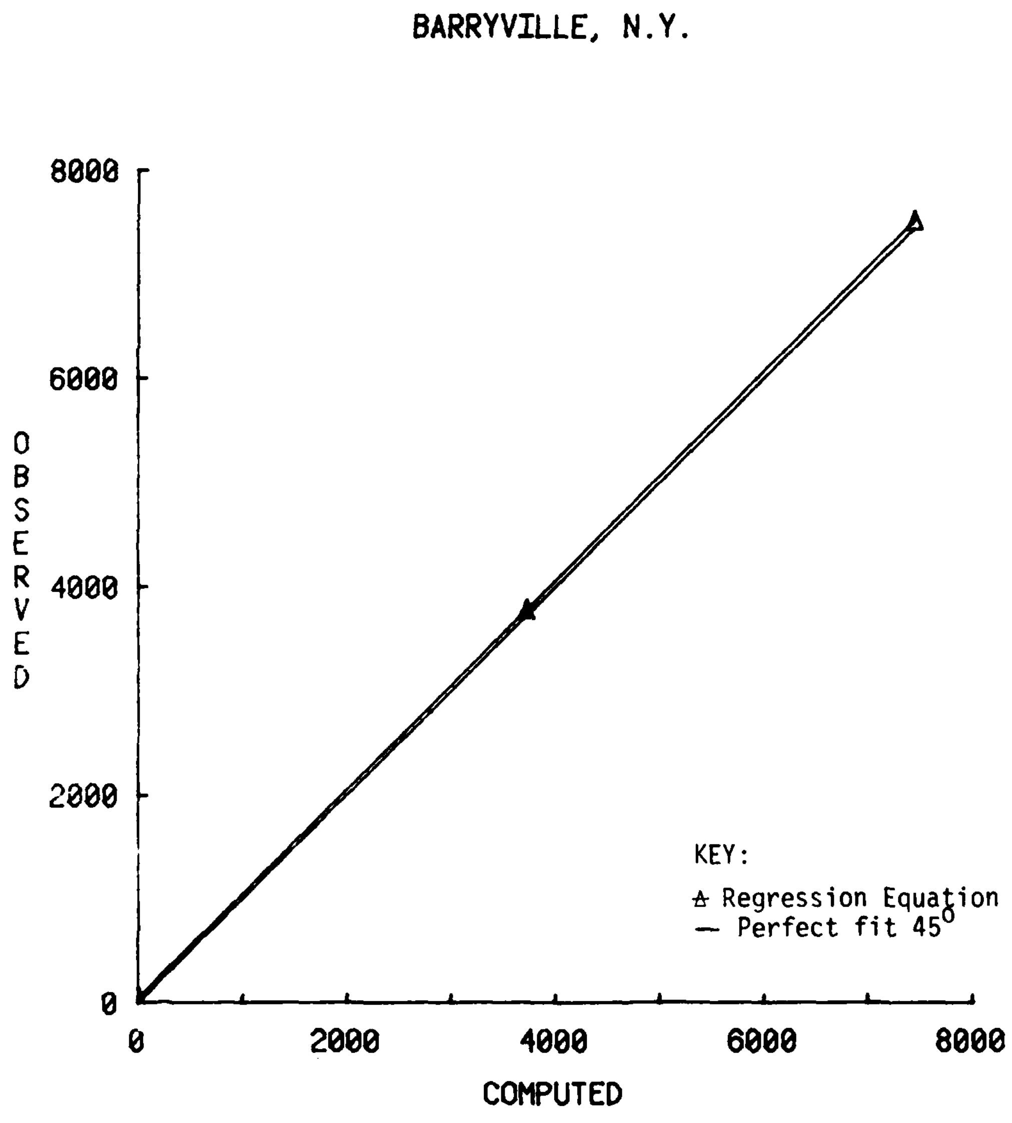

FIGURE II-4. Correlation Accuracy Check: 01428500
Delaware River near Barryville, NY

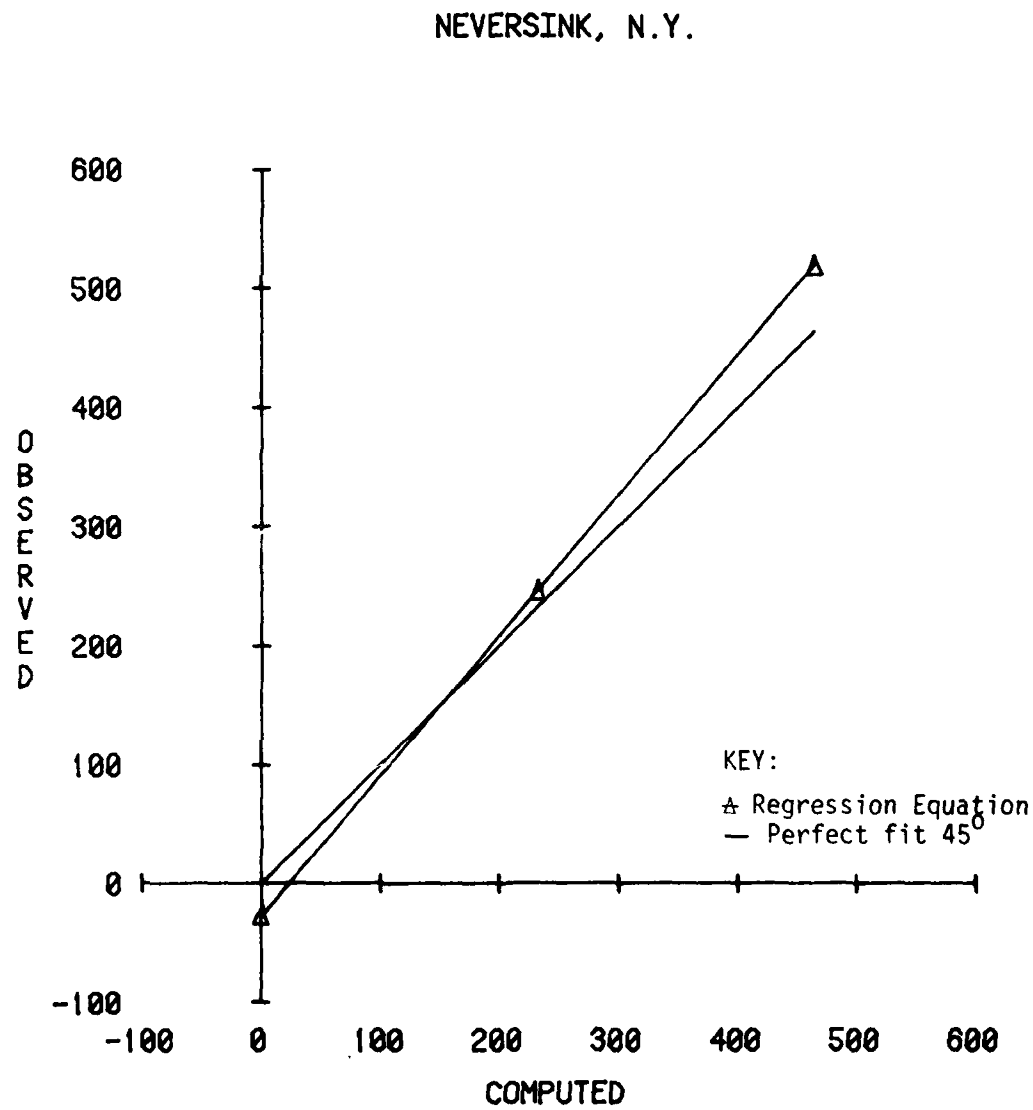

FIGURE II-5. Correlation Accuracy Check: 01436000
Neversink River at Neversink, NY

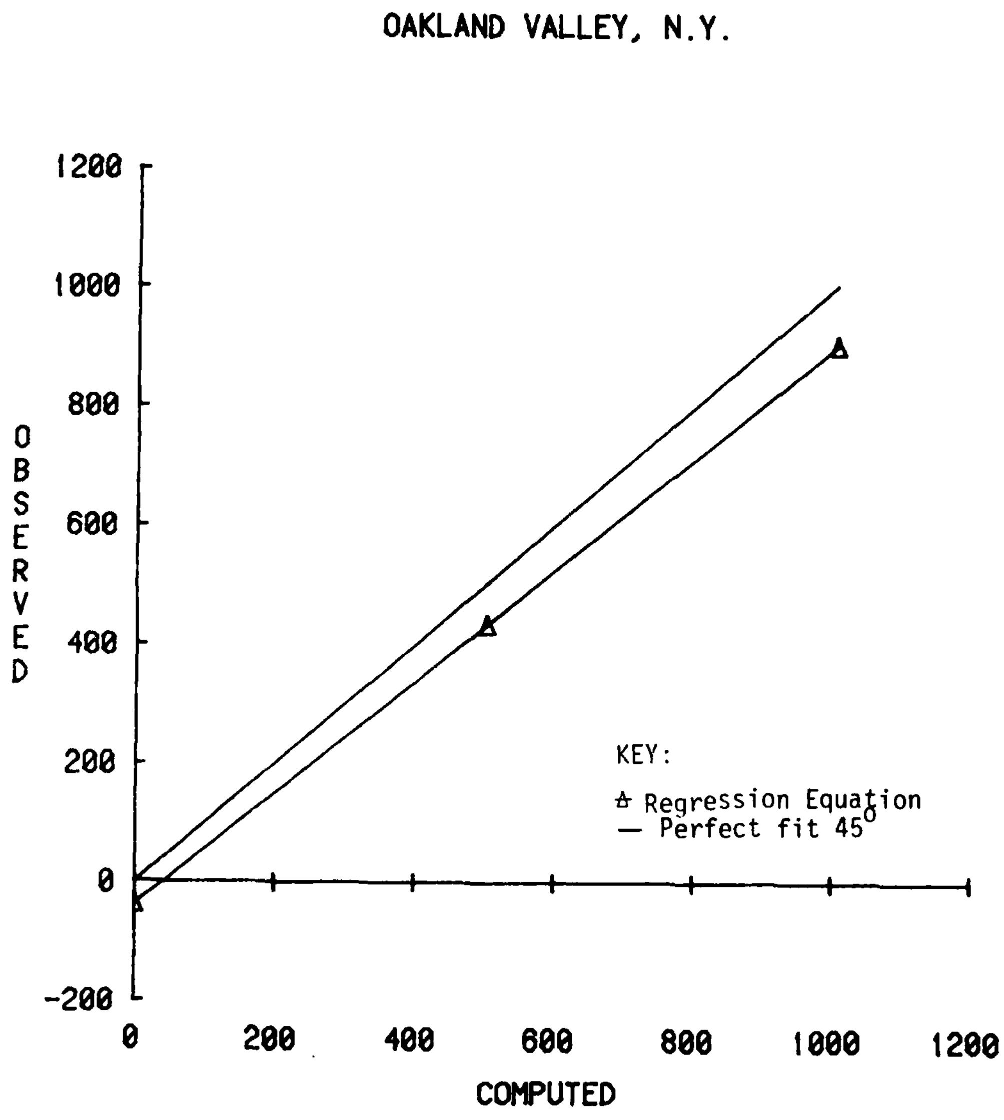

FIGURE II-6. Correlation Accuracy Check: 01437000
Neversink River at Oakland Valley, NY

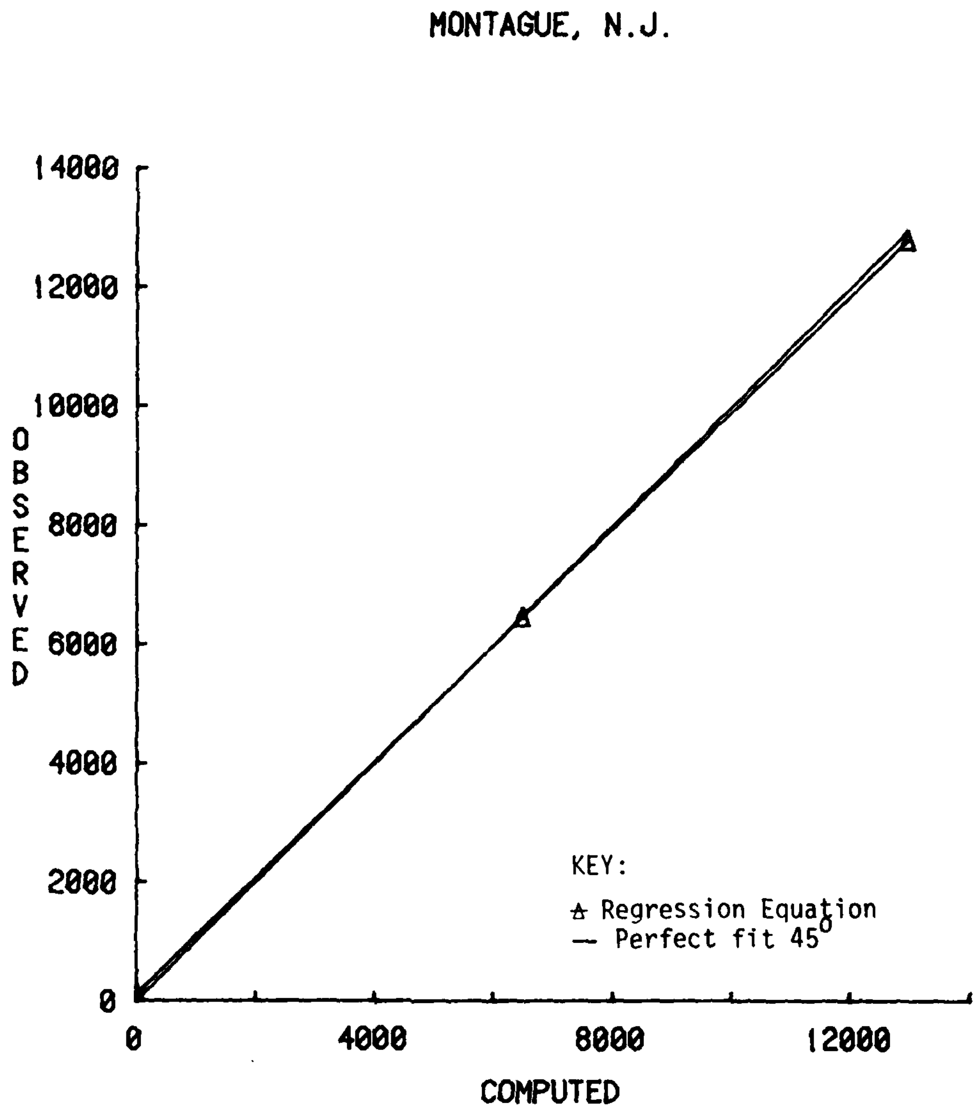

FIGURE II-7. Correlation Accuracy Check: 01438500
Delaware River at Montague, NJ

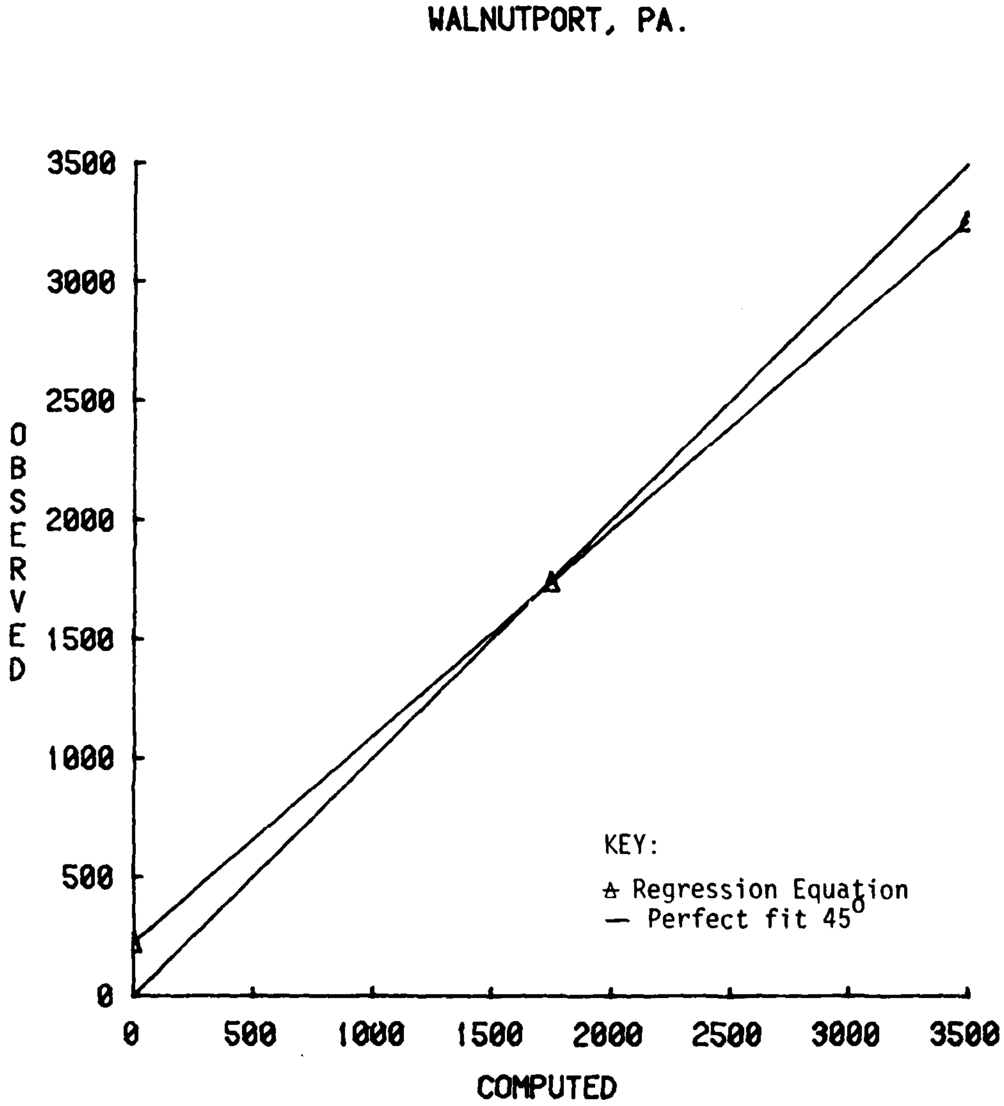

FIGURE II-8. Correlation Accuracy Check: 01451000
Lehigh River at Walnutport, PA

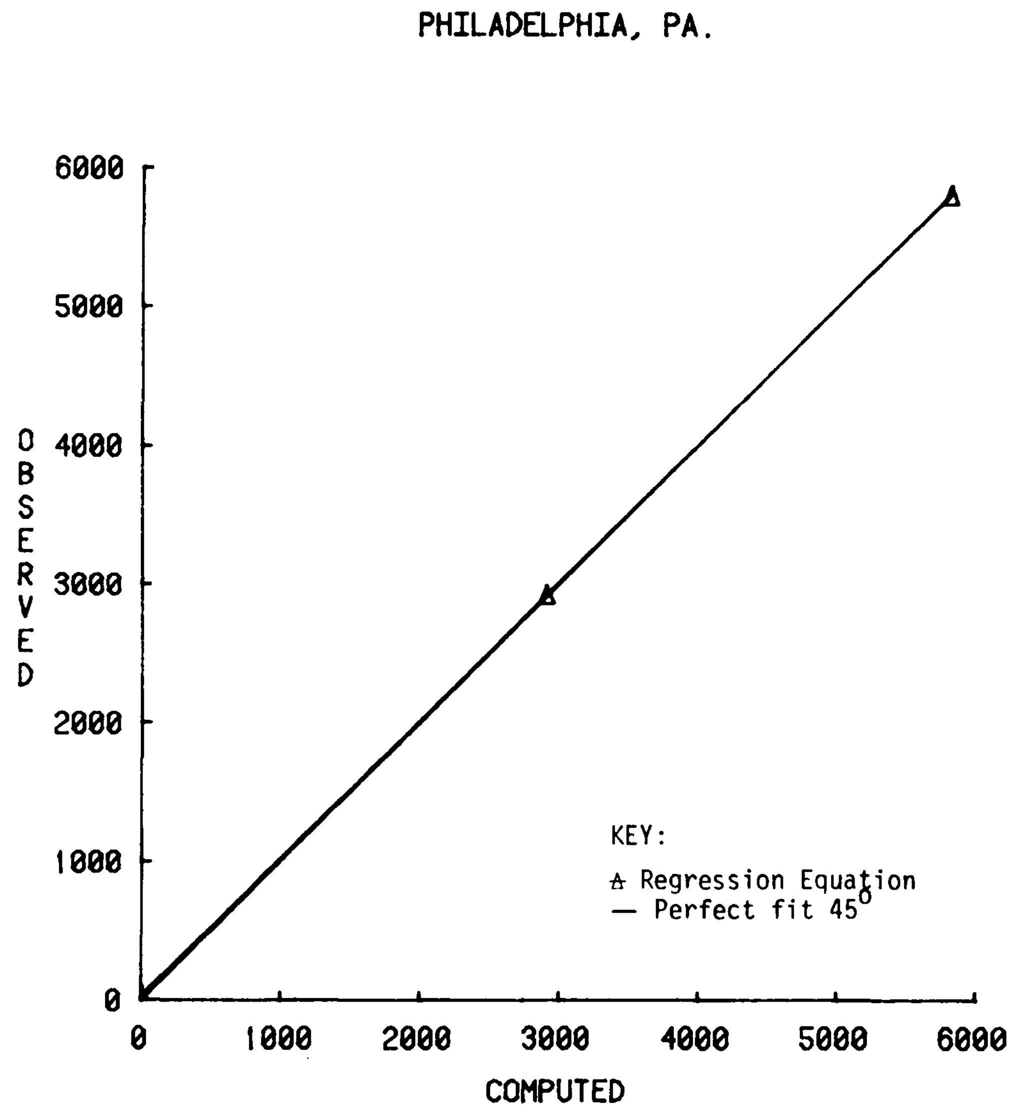

FIGURE II-9. Correlation Accuracy Check: 01474500
Schuylkill River at Philadelphia, PA

III. NATURAL FLOW MODEL

PURPOSE OF THE NATURAL FLOW MODEL

The purpose of the natural flow model is to negate the effect of all existing reservoirs (except the Wallenpaupack Reservoir and the Mongaup Reservoir system) in order to develop natural daily flows at key stations in the basin for the 50-year base period of record. Natural daily flow duration and low flow frequency analyses are performed at those key stations.

The natural flow model consists of a branching network of nodes as shown on Figure II-1. Most nodes are also USGS surface water stations. The model is driven by a set of natural incremental inflows to each node. These incremental inflows are combined with a simple linear lag function from node to node to produce natural daily flows. The model begins at the most upstream nodes on each day. The natural inflows to these headwater nodes is lagged to downstream nodes while the inflow between the nodes is added, producing a daily natural flow at the lower nodes. It is very often the case that the headwater nodes are existing reservoirs.

The natural inflows to the reservoirs are taken from the analyses described in Chapter II. The incremental inflows at the interior nodes are determined by subtracting the routed recorded or extended flows of an upstream node from a downstream node. This procedure assumes that the natural inflow between two adjacent nodes is independent of regulation. These natural incremental inflows drive the natural and regulated flow models. The natural and regulated flow models assume identical rainfall-runoff as that of the 50-year base period.

MODEL OVERVIEW

The basic architecture of the natural flow model is complicated considerably by the requirements of this particular project. The concepts of the model are easy to comprehend but the extremely large data set which is used as input data has made it necessary to disaggregate the various components of the model to minimize redundant calculations. To this end the model is divided into several completely independent programs. Many of these programs are simply processors which manipulate the data to insure efficient and less costly simulation. Table III-1 highlights these processors and indicates the numerous tapes used in this project. The various input files, programs and output files are executed in the order shown in the table. The following describes the various procedures followed in each of these eight programs.

Program SORT

The first step of the simulation is to preprocess the input data into a format which is compatible with the other programs. The raw data in its most basic form is daily discharge as recorded by the USGS. This data is provided on a card image magnetic tape using the format depicted in Figure III-1. Four cards are required for each month of daily flows. Each card has the station number, year and month. Eight days of flow data are given on each of the four cards except the last which has the remaining 25-31 day flows. This tape is ordered "by station, by date," and an example is shown in Figure III-2. The first eight digit number after the card type identifier "3" is the station number (01479000) which is followed by the year, month, card number (1 through 4), and the daily flows. Card type "2," shown in the middle of the figure is contained in the USGS data at the beginning of each water year. It contains the station number (01479000), the parameter code (00060 for stream flow in cfs), the statistics code (00003 for mean value for each day) and "ENT."

The shear volume of data (93,218 records) required for this project makes this format unacceptable. For this reason the SORT program reorders the data set into a "by date, by station" format, as shown in Figure III-3.

TABLE III-1

COMPUTER PROGRAMS, INPUT FILES AND OUTPUT FILES

Program	Description	Input Tape Number or File	Output Tape Number or File
SORTGS	Merges two input tapes and changes order from by station by date to by date by station	21772 (original USGS) 51317 (additional USGS)	24610
FILLIN	Uses recorded data and correlation equations to produce 50 years of daily flow data for each station	KINGS 60 (D&R Canal 1960 Data) TOCKSILE (USGS Tocks Island Data) PEPACT (NYC Inflows to Pepacton Res.) CANNON (NYC Inflows to Cannonsville Res.) NVRSNK (NYC Inflows to Neversink Res.) 23010 24610	20585
INFLOW	Disagregates recorded and extended data from FILLIN program by lagging and subtracting to produce 50 years of natural incremental flows	20585	20979
NATFLO	Combines natural incremental inflows to simulate 50 years of natural flow conditions	20979	26201 (unformatted output) 26202 (copy of paper output)
REGFLO	Combines natural incremental inflows under regulated conditions (Uses NYC inflows to Pepacton, Cannonville, and Neversink Res.)	20979	24241 (unformatted output) 26197 (copy of paper output)
REFORM1	Formats the binary output for the model nodes to be analyzed statically from NATFLO and REGFLO programs to card image records	26201 24241	23992 23721
SORT	Changes order of output from REFORM runs from by date by station to by station by date	23992 23721	24199 23724
REFORM2	Formats and combines into final USGS form the outputs from the SORT runs onto one tape (as input to USGS statistical package A969)	24199 23724	23705

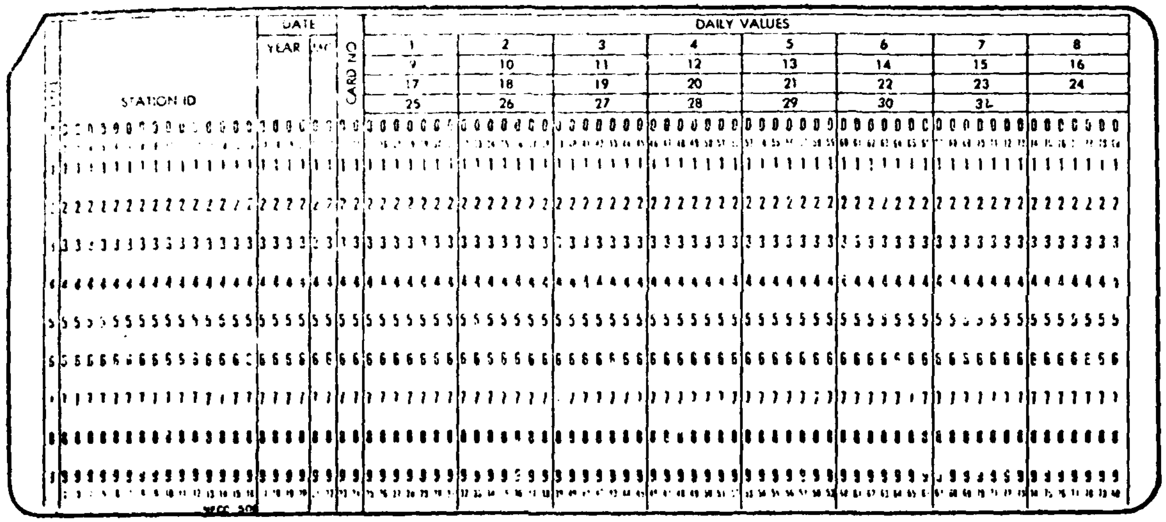

Figure 6.—Data card.

Column(s)	*Description*
1	Card type – – always a '3'.
2–16	Station identification number (right justified).
17–20	Calendar year date.
21–22	Month designation. '01' is January; '12' is December.
23–24	A two-digit number representing the fraction of the month the daily values represent.

Code	*Days*
01	1–8
02	9–16
03	17–24
04	25–31

25–80	Daily data. Eight seven-column fields that contain the daily data for the designated day. Decimal points are punched when applicable. Blank fields indicate that there are no data available for that particular day.

FIGURE III-1. U.S.G.S. Card Image Format

	Station Yr. Mo. Card No.								
3	0147900019430601	100.00	110.00	100.00	96.00	89.00	85.00	87.00	96.00
3	0147900019430602	148.00	118.00	101.00	90.00	90.00	94.00	79.00	79.00
3	0147900019430603	80.00	180.00	84.00	72.00	69.00	66.00	85.00	63.00
3	0147900019430604	62.00	59.00	225.00	348.00	156.00	120.00		
3	0147900019430701	77.00	69.00	68.00	65.00	94.00	154.00	79.00	76.00
3	0147900019430702	111.00	77.00	636.00	179.00	104.00	87.00	82.00	69.00
3	0147900019430703	63.00	63.00	59.00	55.00	87.00	63.00	72.00	55.00
3	0147900019430704	55.00	63.00	60.00	53.00	49.00	51.00	48.00	
3	0147900019430801	44.00	43.00	42.00	40.00	46.00	42.00	38.00	37.00
3	0147900019430802	37.00	38.00	37.00	35.00	37.00	47.00	37.00	32.00
3	0147900019430803	31.00	30.00	30.00	29.00	29.00	29.00	29.00	27.00
3	0147900019430804	27.00	26.00	26.00	29.00	30.00	31.00	30.00	
3	0147900019430901	28.00	26.00	26.00	29.00	32.00	30.00	26.00	26.00
3	0147900019430902	24.00	22.00	22.00	22.00	22.00	22.00	26.00	24.00
3	0147900019430903	22.00	22.00	21.00	22.00	24.00	26.00	25.00	24.00
3	0147900019430904	24.00	21.00	22.00	21.00	22.00	23.00		
2	01479100	0006000003				ENT			
3	0147900019431001	131.00	105.00	46.00	34.00	32.00	32.00	30.00	32.00
3	0147900019431002	30.00	30.00	30.00	30.00	30.00	30.00	30.00	146.00
3	0147900019431003	138.00	46.00	38.00	34.00	32.00	34.00	32.00	33.00
3	0147900019431004	37.00	258.00	329.00	212.00	144.00	79.00	62.00	
3	0147900019431101	54.00	52.00	290.00	104.00	72.00	64.00	61.00	67.00
3	0147900019431102	786.00	140.00	107.00	102.00	84.00	74.00	69.00	67.00
3	0147900019431103	62.00	60.00	58.00	58.00	59.00	81.00	64.00	59.00
3	0147900019431104	56.00	56.00	55.00	54.00	54.00	52.00		
3	0147900019431201	52.00	52.00	53.00	52.00	50.00	51.00	50.00	54.00
3	0147900019431202	53.00	50.00	48.00	44.00	43.00	42.00	41.00	40.00
3	0147900019431203	40.00	40.00	40.00	40.00	40.00	40.00	41.00	42.00
3	0147900019431204	46.00	292.00	556.00	99.00	72.00	50.00	45.00	
3	0147900019440101	40.00	45.00	1140.00	2240.00	256.00	621.00	146.00	106.00
3	0147900019440102	83.00	70.00	68.00	66.00	65.00	65.00	65.00	65.00
3	0147900019440103	65.00	65.00	66.00	64.00	64.00	71.00	106.00	92.00
3	0147900019440104	64.00	64.00	64.00	75.00	79.00	70.00	64.00	
3	0147900019440201	60.00	55.00	62.00	61.00	56.00	59.00	55.00	52.00
3	0147900019440202	52.00	50.00	62.00	50.00	50.00	73.00	368.00	124.00
3	0147900019440203	84.00	124.00	84.00	70.00	68.00	68.00	100.00	82.00
3	0147900019440204	72.00	81.00	127.00	90.00	82.00			

FIGURE III-2. Example of Recorded U.S.G.S. Data Ordered by Station by Date

```
Station  Yr.  Mh. Card No.
3    0142100019280201 700.00 700.00 700.00 700.00 850.00 800.00 800.001500.00
3    0142650019280201 610.00 560.00 510.00 535.00 610.00 535.00 585.001010.00
3    0143050019280201 200.00 190.00 200.00 243.00 442.00 389.00 302.00 558.00
3    0143200019280201 490.00 481.00 533.00 591.00 166.00 552.00 573.00 412.00
3    0143400019280201 2970.003200.003200.003080.002970.002540.002440.003200.00
3    0144650019280201 5690.005690.005400.005120.005990.006620.006940.008320.00
3    0144800019280201 300.00 300.00 335.00 505.00 660.00 525.00 485.00 660.00
3    0145300019280201 1600.001600.001600.001780.003220.002790.002380.004300.00
3    0145600019280201  70.00  70.00  75.00 108.00 152.00 172.00 152.00 260.00
3    0145700019280201 205.00 196.00 186.00 218.00 353.00 303.00 297.001060.00
3    0145750019280201 8080.007760.007440.007440.009700.00 10800.9390.00 15000.
3    0146350019280201 9000.009000.009500.00 10000. 13000. 14000. 12000. 16000.
3    0146400019280201  79.00  76.00  71.00  79.00 158.00 172.00 156.00 574.00
3    0146700019280201 202.00 202.00 192.00 182.00 259.00 284.00 271.00 455.00
3    0146950019280201  54.00  50.00  50.00  60.00 120.00  67.00  64.00 208.00
3    0147200019280201 1800.001500.001300.001900.002850.002700.002280.005560.00
3    0147300019280201 400.00 340.00 340.00 400.001140.002130.00 920.007080.00
3    0142100019280202 3000.001900.001700.001400.001200.001300.008000.002940.00
3    0142650019280202 1220.001080.001080.001010.00 800.00 936.003340.002230.00
3    0143050019280202 850.00 558.00 406.00 354.00 354.00 389.001770.00 675.00
3    0143200019280202 579.00 410.00 108.00 144.00 374.00 520.00 448.00 492.00
3    0143400019280202 9220.007580.006460.005760.004800.004220.00 15200. 21300.
3    0144650019280202 9050.00 13700. 13200.9810.007610.006940.00 15000. 29400.
3    0144800019280202 1170.001000.00 855.00 615.00 505.00 660.002340.001560.00
3    0145300019280202 5800.004000.003000.002680.002180.002580.00 10500.5800.00
3    0145600019280202 346.00 295.00 260.00 236.00 225.00 236.00 490.00 401.00
3    0145700019280202 625.00 506.00 444.00 408.00 376.00 569.001080.00 665.00
3    0145750019280202 17300. 17700. 17300. 13700. 10800. 10700. 26800. 37000.
3    0146350019280202 20000. 21300. 20500. 16500. 12300. 10400. 22100. 30400.
3    0146400019280202 535.00 419.00 290.00 227.00 182.00 176.00 391.00 390.00
3    0146700019280202 485.00 590.00 500.00 365.00 350.00 323.00 485.00 455.00
3    0146950019280202 195.00 100.00  89.00  80.00  67.00 370.00 370.00 195.00
3    0147200019280202 8990.005560.003840.003160.002700.003160.00 14800.5560.00
3    0147300019280202 5210.001630.00 738.00 580.00 450.001020.003710.00 970.00
```

FIGURE III-3. Example of Sorted U.S.G.S. Data Ordered by <u>Date</u> by <u>Station</u>

The first eight digit numbers after the card type "3" are the station numbers. This example shows the flows of days 1-8 (Card No. 1) for February 1928 (192802 in the figure) at several stations. They are followed by the flows for days 9-16 (Card No. 2) for February 1928 for several stations. This reformatted tape eliminated the necessity of rereading the entire data set for each fill-in operation.

The heart of this program is a system subroutine called SORTMERGE. The advantage of the system subroutine is extreme efficiency relative to procedures using conventional FORTRAN sort routines. Unfortunately system subroutines are also system specific. Thus it will be necessary to make some slight modifications before this program could be executed on a system other than the Control Data Corporation (CDC) CYBER 176 system used in this study.

The output tape generated in SORT is used as input data for FILLIN.

Program FILLIN

The correlation and regression analysis used to both extend short term stations and eliminate the effect of regulation on long term stations is described in detail in Chapter II. FILLIN is the program which applies the resultant correlation equations to extend the existing USGS record thereby obtaining a complete 50-year record for the gaging stations. Because of problems with data acquisition and stations with special considerations, FILLIN requires some special input tapes and files to complete the period of record of all stations. The New York City Reservoir daily inflows are also written onto the output tape to consolidate all of the input data. Figure III-4 is an example of the filled in data set. The output tape generated by this program is of the same general format as the original USGS tape except that it is ordered by date by station. This tape, however, includes 50 years of records for all stations. The records of those stations which are not required for further analysis are filled with 999999 where recorded data are not available. The output tape from FILLIN is used as input data for INFLOW.

Station Yr. Mo.Card No.

3	143500019271103	999999.	999999.	999999.	999999.	999999.	999999.	999999.	999999.
3	143600019271103	396.	1649.	834.	576.	499.	445.	407.	499.
3	143700019271103	798.	3634.	1761.	1189.	1020.	904.	822.	1020.
3	143850019271103	8495.	50407.	47586.	30006.	23378.	18555.	14170.	14170.
3	144020019271103	999999.	999999.	999999.	999999.	999999.	999999.	999999.	999999.
3	144550019271103	10600.	33100.	58800.	35600.	25000.	19900.	17900.	15900.
3	144750019271103	999999.	999999.	999999.	999999.	999999.	999999.	999999.	999999.
3	144772019271103	999999.	999999.	999999.	999999.	999999.	999999.	999999.	999999.
3	144780019271103	1063.	4795.	2931.	1746.	1674.	1478.	1227.	1164.
3	144800019271103	1110.	5370.	3270.	1940.	1860.	1640.	1360.	1290.
3	144936019271103	999999.	999999.	999999.	999999.	999999.	999999.	999999.	999999.
3	144980019271103	242.	857.	581.	381.	368.	332.	286.	274.
3	145000019271103	295.	1113.	733.	472.	456.	410.	350.	335.
3	145034019271103	151.	352.	567.	474.	383.	294.	241.	241.
3	145050019271103	175.	1107.	660.	552.	445.	341.	280.	280.
3	145100019271103	2274.	14563.	8646.	7220.	5821.	4455.	3654.	3654.
3	145180019271103	41.	584.	367.	202.	147.	128.	104.	82.
3	145200019271103	58.	944.	509.	281.	296.	180.	145.	116.
3	145330019271103	3000.	16000.	10000.	8500.	7000.	5500.	4600.	4600.
3	145470019271103	999999.	999999.	999999.	999999.	999999.	999999.	999999.	999999.
3	145600019271103	172.	508.	610.	580.	550.	520.	490.	490.
3	145700019271103	429.	906.	950.	861.	776.	754.	716.	670.
3	145750019271103	12300.	41300.	71000.	47600.	34400.	28400.	24500.	21700.
3	145950019271103	562.	3952.	323.	187.	121.	121.	100.	82.
3	146050019271103	-50.	-50.	-50.	-50.	-50.	-50.	-50.	-50.
3	146350019271103	14400.	37500.	74800.	54500.	37600.	30400.	26500.	20500.
3	146400019271103	110.	247.	198.	202.	204.	185.	153.	128.
3	146450019271103	92.	203.	206.	216.	173.	179.	146.	138.
3	146550019271103	838.	3303.	568.	386.	284.	284.	248.	216.
3	146700019271103	136.	297.	297.	310.	259.	259.	213.	202.
3	146750019271103	157.	445.	311.	240.	203.	189.	154.	157.
3	146795019271103	64.	382.	257.	176.	144.	132.	115.	99.
3	146850019271103	417.	1283.	872.	658.	551.	508.	409.	417.
3	146950019271103	150.	658.	400.	275.	217.	195.	146.	150.
3	147000019271103	388.	1159.	800.	607.	509.	471.	380.	388.
3	147050019271103	1160.	3341.	2589.	1905.	1569.	1438.	1134.	1160.
3	147075619271103	125.	1557.	435.	540.	404.	357.	294.	238.
3	147096019271103	180.	1324.	853.	558.	447.	406.	349.	296.
3	147100019271103	223.	1495.	982.	556.	550.	484.	419.	359.
3	147150019271103	990.	9080.	4840.	3510.	2800.	2560.	2230.	1900.

FIGURE III-4. Example of the Filled-In Data Set

Program INFLOW

This program is perhaps the most sensitive and, therefore, most important facet of the entire simulation process. The output tape from this processor drives both the natural flow model and the regulated flow model.

The actual mechanics of this program are discussed in the subsection entitled Incremental Runoff and Routing Procedures. Incremental flows are calculated by lagging and subtracting filled-in flow records of adjacent stations. When the incremental inflows at all model nodes which are USGS stations are realistically represented, the inflows at nodes which are not USGS stations are calculated using specific prorating procedures. Inflows to three USGS stations whose records could not be extended (Callicoon, Tocks Island, and Glendon) are also calculated using specific prorating procedures. The prorating procedures used to calculate inflows at nodes which are not USGS stations or are USGS stations whose record could not be extended are presented on Figure III-5. For example, the incremental inflow to Callicoon is calculated by subtracting the flows at Fishs Eddy and Hale Eddy from the flow at Barryville and multiplying this value by a drainage area ratio. The drainage area ratio is determined by subtracting the drainage areas of Fishs Eddy and Hale Eddy from the drainage area of Callicoon and dividing this result by the value obtained when the drainage areas of Fishs Eddy and Hale Eddy are subtracted from the drainage area of Barryville.

The output tape supplies the input data to both the natural and regulated models. An example of the incremental inflow file format is shown in Figure III-6.

Program NATFLO

To this point in the simulation sequence, all of the programs have been data preprocessors. NATFLO, on the other hand, is the natural flow model. It takes the inflow generated in INFLOW, routes them through the system using a linear lag formulation and creates the output in

INCREMENTAL INFLOWS TO:	=	TOTAL FLOWS OF:	x	DRAINAGE AREA RATIO:
Callicoon		Barryville - Fishs Eddy - Hale Eddy		(Callicoon - Fishs Eddy - Hale Eddy)/ (Barryville - Fishs Eddy - Hale Eddy)
Tocks Island		Belvidere - Montague		(Tocks Island - Montague)/ (Belvidere - Montague)
Glendon		Bethlehem - Walnutport - Allentown		(Glendon - Bethlehem)/ (Bethlehem - Walnutport - Allentown)
Pt. Pleasant		Pipersville		(Pt. Pleasant - Riegelsville - Pipersville)/(Pipersville)
Torresdale		Assunpink + Extonville + Langhorne + Pemberton		(Torresdale - Trenton - Assunpink - Extonville - Langhorne - Pemberton)/ (Assunpink + Extonville + Langhorne + Pemberton)
Pier 11 North		Assunpink + Extonville + Langhorne + Pemberton		(Pier 11 North - Torresdale)/ (Assunpink + Extonville + Langhorne + Pemberton)
Limerick		Philadelphia - Pottstown		(Limerick - Pottstown)/ (Philadelphia - Pottstown)
Delaware & Schuylkill Conference		Assunpink + Extonville + Langhorne + Pemberton		(Confluence - Pier 11 North - Philadelphia)/ Assunpink + Extonville + Langhorne + Pemberton)
Delaware at Chester		Chester Creek		(Delaware at Chester - Schuylkill Confluence - Chester Creek)/(Chester Creek)
Delaware Memorial Bridge		*Wilmington* + *Wooddale* + Newark		(D.M.B. - Delaware at Chester - *Wilmington* - Wooddale - Newark)/(Wilmington + Wooddale + Newark)

FIGURE III-5. *Prorating Procedures For Incremental Inflows*

Yr. Mo. Card No.								
280301	344.	177.	152.	194.	128.	149.	147.	134.
280301	392.	315.	274.	242.	250.	210.	206.	202.
280301	564.	230.	249.	318.	210.	245.	240.	220.
280301	203.	137.	180.	154.	146.	128.	131.	122.
280301	105.	114.	105.	102.	102.	94.	94.	90.
280301	497.	445.	414.	399.	399.	368.	359.	352.
280301	165.	147.	137.	133.	133.	123.	123.	118.
280301	84.	[illegible]	80.	77.	77.	72.	72.	69.
280301	567.	[illegible]	545.	524.	524.	492.	492.	461.
280301	[illegible]	62.	62.	64.	68.	55.	63.	57.
280301	625.	[illegible]	521.	503.	503.	464.	464.	444.
280301	434.	424.	341.	278.	245.	224.	224.	203.
280301	632.	[illegible]	545.	503.	503.	464.	464.	388.
280301	268.	[illegible]	238.	223.	196.	150.	207.	202.
280301	345.	[illegible]	220.	183.	232.	201.	250.	146.
280302	[illegible]	[illegible]	223.	224.	811.	1562.	931.	544.
280302	297.	297.	297.	740.	1437.	2693.	574.	594.
280302	352.	319.	318.	318.	748.	3332.	1910.	957.
280302	81.	72.	80.	80.	323.	1493.	301.	64.
280302	179.	171.	192.	227.	1475.	3902.	-753.	-306.
280302	[illegible]	61.	62.	54.	101.	268.	159.	110.
280302	53.	54.	55.	46.	35.	291.	159.	105.
280302	47.	[illegible]	48.	41.	32.	214.	135.	77.
280302	[illegible]	[illegible]	111.	39.	222.	705.	257.	187.
280302	419.	[illegible]	[illegible]	[illegible]	372.	363.	391.	397.
280302	131.	653.	[illegible]	[illegible]	1417.	-729.	-741.	1986.
280302	[illegible]	217.	215.	102.	318.	702.	459.	341.
280302	[illegible]	201.	205.	[illegible]	[illegible]	1039.	301.	255.
280302	[illegible]	164.	174.	247.	[illegible]	586.	516.	672.
280302	[illegible]	642.	434.	331.	637.	527.	1339.	1178.
280302	1472.	[illegible]	922.	737.	1289.	977.	3569.	2177.
280302	[illegible]	[illegible]	258.	[illegible]	355.	639.	729.	729.
280302	88.	[illegible]	80.	88.	104.	163.	187.	187.
280302	75.	[illegible]	70.	[illegible]	106.	207.	101.	122.
280302	12.	[illegible]	12.	12.	17.	53.	31.	20.
280302	[illegible]	[illegible]	595.	[illegible]	[illegible]	[illegible]	1813.	773.
280302	55.	[illegible]	53.	57.	[illegible]	174.	126.	95.
280302	93.	27.	27.	25.	44.	75.	54.	41.
280302	[illegible]	587.	161.	494.	710.	1614.	490.	-169.
280302	101.	107.	42.	198.	194.	418.	127.	-44.
280302	[illegible]	114.	108.	116.	102.	192.	182.	162.
280302	147.	[illegible]	137.	125.	227.	213.	182.	159.
280302	673.	[illegible]	814.	1140.	1110.	1056.	775.	1645.
280302	49.	[illegible]	56.	108.	374.	349.	187.	133.
280302	[illegible]	17.	18.	52.	133.	114.	51.	44.
280302	-50.	[illegible]	-55.	-50.	-50.	-50.	-50.	-50.
280302	-590.	3553.	-109.	-94.	-1638.	551.	-1068.	2268.
280302	[illegible]	129.	148.	211.	222.	203.	178.	151.

FIGURE III-6. Example of Incremental Inflow File

several formats. These various output formats are designed to facilitate any further analysis which may be required.

The daily flows for each month are printed ι in yearly tables. The tables for each year also include for each month, the minimum, maximum, mean and total daily flows and the standard deviation. Figure III-7 is an example printout showing the 1953 daily discharges for the Delaware River at Barryville. As a backup, an unformatted file is saved on magnetic tape. This tape is an efficient means of recalling the stations, dates and flows to be reformatted in the remaining post-processors. It can also be used to create multiple copies of the results without rerunning the entire program.

Programs REFORM1/SORT/REFORM2

These remaining three programs are post-processors which reformat the model output into a form compatible with the USGS WATSTORE Daily Values statistics program A969 which produces duration and frequency tables. The first program converts the binary file to standard USGS card image format ordered "by date, by station." The second program reorders the file to "by station, by date" and the last program simply inserts the annual header cards required by the A969 program. At this point, the model output is ready for processing by the USGS A969 program.

INCREMENTAL RUNOFF AND ROUTING PROCEDURES

As previously stated, historical incremental runoff (or inflow) drives the natural and regulated flow models.

The entire simulation process is not intended to be a rainfall/runoff processor. The purpose of this modelling effort is to focus on the low flow events in the basin. Rainfall-runoff processors by their formulation, tend to misrepresent small rainfall events and groundwater accretion. This being the case, rather than simulating runoff from rainfall, the recorded and extended USGS record is used to determine the historical runoff between adjacent gaging stations. This

CDM/ WATER RESOURCES ENGINEERS • • • • P H A S E 1 • • • • NATURAL FLOW
SPRINGFIELD, VIRGINIA • DELAWARE RIVER • SIMULATION MODEL
NODE 2045 • • • DELAWARE RIVER AT BARRYVILLE 01428500

------------------------------------TOTAL DAILY DISCHARGE SIMULATED FOR 1953 (CFS)------------------------------------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	2000.23	6378.72	4770.10	8729.36	9308.95	2729.91	1041.38	332.73	142.46	284.45	2081.12	2860.02
2	1849.63	5800.54	3700.81	7930.24	14200.31	2348.70	953.36	321.73	139.07	265.52	1740.02	2630.24
3	1799.99	4699.04	3299.39	7570.09	12898.90	2020.02	905.32	316.23	133.95	243.14	1479.17	2390.50
4	1800.63	4399.87	4700.22	6459.67	10700.99	1789.86	777.84	313.74	125.75	228.58	1299.73	2160.52
5	1598.85	3899.33	7079.80	5969.68	9810.29	1700.19	689.59	315.88	137.21	227.97	1160.63	2119.06
6	1399.77	3301.44	5569.89	5559.95	12000.85	1760.85	643.09	316.91	302.64	338.10	1039.79	2855.29
7	1299.03	5000.27	4400.15	8590.16	9930.65	1960.62	617.20	306.77	1322.48	854.30	1019.95	14525.67
8	1249.23	8249.98	3699.99	13899.98	9709.23	2390.27	585.40	299.48	1893.87	901.33	1028.53	18400.91
9	1079.23	6480.76	3199.70	10600.90	9530.05	2039.42	646.69	297.52	1041.74	702.58	1019.79	11700.13
10	1599.13	5000.53	3000.52	9311.37	8349.35	1659.61	703.31	309.21	988.01	574.54	1020.40	11099.70
11	2750.65	4100.26	2599.78	9600.69	6939.93	1410.17	697.05	317.01	734.64	502.63	1089.49	12600.26
12	3900.14	3899.97	2600.22	7889.71	5930.01	1250.47	647.93	312.63	593.91	595.17	1179.64	8960.34
13	3300.62	3799.97	2880.18	7539.82	5160.17	1250.07	575.14	307.81	811.91	552.32	1269.85	8300.50
14	2899.71	3500.45	3829.75	8420.07	5400.78	1559.84	526.70	713.78	1138.72	507.40	1321.06	8370.78
15	2600.12	3399.76	5359.39	7060.37	5159.54	1519.59	501.54	869.66	1141.25	487.57	1330.44	10399.51
16	2600.53	3399.55	13700.29	6319.61	5109.95	1310.50	476.55	606.14	897.56	473.69	1319.93	9010.59
17	3400.09	3200.57	13199.71	7030.19	5599.57	1119.95	451.50	409.40	743.05	441.55	1330.64	6799.27
18	4600.47	2799.79	9459.89	6259.87	6969.30	999.02	427.52	312.38	635.75	432.62	1420.67	5200.96
19	7599.32	2599.76	9630.21	6380.46	6090.32	930.92	419.94	350.50	552.60	402.25	1419.59	3899.38
20	6600.02	2599.94	9778.99	6439.47	5130.64	873.33	492.18	379.82	506.85	388.99	1369.35	3799.85
21	5720.65	9566.98	8090.25	6030.16	4459.83	820.76	468.09	334.20	473.80	375.85	1350.19	3999.45
22	5130.33	17353.06	6820.03	5510.19	3951.08	769.77	455.09	296.00	450.72	359.43	1329.20	3900.65
23	4520.69	12800.12	5120.25	4979.06	4150.92	716.17	493.02	271.86	416.71	349.37	2712.19	3800.39
24	13920.38	9169.17	7849.91	4539.90	4689.88	743.52	494.20	250.19	405.42	336.77	4117.68	3099.21
25	38780.33	7859.98	17000.50	4339.51	3660.92	684.59	456.26	227.98	383.65	344.66	4590.62	2599.09
26	24000.23	6770.45	19200.22	5709.59	3200.77	624.20	485.27	213.94	367.60	353.60	5158.84	2450.38
27	13400.79	6150.31	19499.70	12999.28	3299.32	727.38	451.57	196.24	346.39	340.66	5320.09	2349.68
28	10400.24	5571.12	17599.55	13599.33	3469.66	780.24	404.13	182.94	328.04	425.77	4200.00	2250.07
29	10200.11	0.00	13500.87	10400.64	2969.47	1556.13	372.59	170.17	319.87	843.19	3639.97	2149.84
30	7200.38	0.00	10500.71	8319.91	2660.33	1659.80	365.50	158.68	301.01	1982.10	3159.80	2080.72
31	6000.53	0.00	9570.02	0.00	2789.52	0.00	339.35	150.67	0.00	2053.87	0.00	1899.73
MIN	1079.23	2599.76	2599.78	4339.51	2660.33	624.20	339.35	150.67	125.75	227.97	1019.79	1899.73
MAX	38780.33	17353.06	19499.70	13899.98	14200.31	2729.91	1041.38	869.66	1893.87	2053.87	5320.09	18400.91
MEAN	6309.75	5963.28	8074.87	7799.64	6552.31	1390.20	566.56	327.81	592.55	553.87	2050.61	5763.31
TOTAL	195602.17	164171.71	250321.11	233989.34	203121.47	41705.85	17563.26	10162.19	17776.63	17169.98	61518.41	178662.73
S DEV	7666.72	3318.06	5002.98	2472.10	3166.61	568.52	171.46	147.23	407.87	421.86	1336.50	4323.86

FIGURE III-7. Example of Model Output

approach is deemed most appropriate since it utilized the best available data and provides the desired results.

The amount of incremental inflow between two adjacent stations as calculated in the INFLOW program is simply the mean daily flow at the downstream station minus the mean daily flow at the upstream station. The upstream flow is lagged prior to subtraction; the amount of lag depends on the time of travel between stations. If the wrong amount of lag is applied to the upstream flow, negative inflows result between stations. But the same lag assumption is used to disaggregate flows in the INFLOW program as is used to combine the inflows in the NATFLO program, so the negative inflows have no effect on the natural flow simulation. The problems with negative inflows occur at nodes just downstream of reservoir sites when regulation is added to the system. In most cases, the conservation releases from the reservoirs are much smaller than the naturally occurring discharges. Thus, a small upstream discharge plus a negative incremental inflow could yield negative or abnormally low discharges at nodes just downstream of reservoir sites. If abnormally low or negative flows were allowed to occur, the statistical portions of this project would become meaningless.

It is well known that time of travel is a function of flow. The actual function, however, is not well defined. Several attempts are made to determine the best lag time function between each pair of nodes. As a baseline case, the first attempt at generating inflow assumes zero lag between all stations. This proves to be wholly inadequate. There are often many days in a row which display negative inflows. The next attempt uses a constant lag between the various stations. While several different constant lags are tried, all prove to be equally unsatisfactory.

The third attempt begins with a derivation based on Manning's Equation, and results in an equation of the form:

$$L = \alpha Q^{\beta} \qquad \text{(III-1)}$$

where

L = flow through time of a given reach,

Q = discharge in that reach at the given time; and

α, β = empirically derived constants.

Unfortunately there is insufficient travel time information to properly determine the coefficients "α" and "β." For this reason, this method also proves to be unsatisfactory.

The final and selected method for lag time determination assumes a linear lag function of the form,

$$L = aQ + b \qquad \text{(III-2)}$$

where

L = flow through time of a given reach,

Q = discharge in that reach at the given time, and

a,b = empirically derived constants.

The constants, a and b, are initially determined from available times of travel and high and low flow data. High and low flow data are readily available for each USGS station. The maximum and minimum discharges which are published in the surface water records are used in determining the constants. The initial values of low and high flow times of travel are developed from the "Report on the Comprehensive Survey of the Water Resources of the Delaware River Basin."[1] Reasonable travel times are selected for each reach. High and low flow times of travel are estimated using the stream miles between stations and average rates of travel when not available in the report. The constant, b, is the low flow time of travel and represents the maximum time between stations. The maximum travel time between stations can

[1] "Report on the Comprehensive Survey of the Water Resources of the Delaware River Basin, Appendix M: Hydrology" U.S. Corps of Engineers, Philadelphia District, 1960.

never be greater than 24 hours, since the model operates with a daily time step. The constant, a, is determined by:

$$a = \frac{\text{Low Flow Travel Time - High Flow Travel Time}}{\text{Low Flow - High Flow}} \qquad \text{(III-3)}$$

and is always a negative value.

The times of travel are further adjusted from the initial values selected. The times of travel are adjusted so that the fewest number of negative inflows are created when the recorded data are lagged and subtracted. Negative inflows are still occasionally produced, but these negatives pose no problem to the model except at those nodes just downstream of an existing or potential reservoir site. Table III-2 shows the final range of lag times used in the modelling effort. The constants "a" and "b" for the lag function are also shown in Table III-2.

The lag function described above is applied in the model simulation in the following manner.

For each day the total flow at, say, node I is the sum of the incremental inflow to the node and the routed flow from the upstream node, I-1. The total routed flow from the upstream node is calculated based on routing a fraction of the day-before flow at the upstream node and routing a fraction of the present-day flow at the upstream node.

The flow at node I for any given day is expressed as:

$$\text{FLOW(I) = INFLOW(I) + QOUT(I-1)* YLAG + Q(I - 1)*(1-XLAG)} \qquad \text{(III-4)}$$

where

FLOW(I)	= Present-day total flow at node I
INFLOW(I)	= Present-day incremental inflow to node I
QOUT(I-1)	= Day-before flow at upstream node
YLAG	= lag function applied to day-before total flow at upstream node

TABLE III-2

RANGE OF HIGH AND LOW FLOW LAG TIMES

AND LAG FUNCTION CONSTANTS

Reach	Lag Time (Hours) Low Flow	High Flow	Lag Function a (in hr/cfs 10^{-3})	Constants b (hours)
Downsville - Fishs Eddy	16	0	-0.6695	16
Fishs Eddy - Barryville	24	6	-0.3377	21
Stilesville - Hale Eddy	6	0	-0.3429	6
Hale Eddy - Barryville	24	6	-0.6429	24
Barryville - Port Jervis	10	3.5	-0.0500	10
Prompton - Lackawaxen at Honesdale	2	0	-0.3413	2
Dyberry at Honesdale - Lackawaxen at Honesdale	1	0	-0.0645	1
Lackawaxen at Honesdale - Hawley	5	2	-0.1613	5
Hawley - Port Jervis	11	5	-0.1156	11
Wilsonville - Port Jervis	4	2	-0.3106	4
Neversink - Oakland Valley	18	0	-0.8072	18
Oakland Valley - Montague	10	2	-0.2667	10
Montague - Belvidere	24	0	-0.0960	24
Belvidere - Riegelsville	4	0	-0.0062	4
White Haven - Walnutport	16	5	-0.2030	16
Beltzville Dam - Walnutport	9	3	-1.1320	9
Palmerton - Walnutport	3	1	-0.1786	3
Walnutport - Bethlehem	16	4	-0.1542	16
Allentown - Bethlehem	4	1	-0.1852	4
Bethlehem - Riegelsville	12	3	-0.0978	12
Hackettstown - Bloomsbury	9	4	-2.3040	9
Bloomsbury - Riegelsville	3	2	-0.1437	3
Riegelsville - Trenton	14	0	-0.0176	14
Pipersville - Trenton	8	5	-0.1875	8
Trenton - Torresdale	9	5	-0.0122	9
Assunpink Cr. at Trenton - Torresdale	9	5	-0.7339	9
Extonville - Torresdale	10	6	-0.7722	10
Langhorne - Torresdale	4	2	-0.0406	4
Pemberton - Torresdale	8	5	-0.1734	8
Pottsville - Landingville	3	1.5	-0.2431	3
Cressona - Landingville	2	0	-1.8180	2
Langingville - Berne	5	2.5	-0.2917	5
Tamaqua - Berne	7	4	-0.3851	7
Berne - Schuylkill at Reading	9	5	-0.0935	4
Schuylkill at Reading - Pottstown	18	11	-0.1827	18
Pottstown - Philadelphia	24	11	-0.2559	24
Graterford - Philadelphia	11	5	-0.1504	11
Philadelphia - Delaware R.	5	2	-0.0312	5
Chester - Delaware R. at Chester	2	1	-0.0694	2
Newark - Delawar Memorial Bridge	8	4	-0.2326	8
Wooddale - Delaware Memorial Bridge	8	3.5	-0.2528	8
Chadds Ford - Wilmington (Brandywine Cr.)	5	2.5	-0.4167	5
Wilmington (Brandywine Cr) - Del. Mem. Br.	3	1.5	-0.2366	3

Q(I - 1) = Present-day total flow of upstream node

(1 - XLAG) = Lag function applied to present-day total flow at upstream node

In the model, the lag function, Equation III-2, is transformed into two expressions. For the day-before flow at the upstream node which is routed and accounted for in the present-day flow at the downstream node the lag function is:

$$YLAG = a * QOUT(I - 1) + b \qquad (III-5)$$

where

YLAG = Fraction of the day-before flow at the upstream node routed to the downstream node

QOUT(I-1) = Day-before flow at upstream node

a,b = Lag Constants

For the present-day flow at the upstream node which is routed and accounted for in the present-day flow at the downstream node the lag function is:

$$XLAG = a * Q(I-1) + b \qquad (III-6)$$

where

XLAG = Fraction of present-day flow at the upstream node which is not routed to downstream node. Fraction of present-day flow which is routed to downstream node is calculated in Equation III-4 as (1 - XLAG).

Q(I-1) = Present-day flow at upstream node

a,b = Lag Constants (identical to a, b in III-5)

Consider the following example. An upstream node (I-1) has a flow of 1500 cfs for the present-day flow and 1000 cfs for the day-before flow. The flows are to be routed to the downstream node (I) with no incremental runoff to the downstream node (INFLOW (I) = 0). The "a" and "b" of the lag function for the reach are -0.0003 and 24, respectively. In the model the constants "a" (hr/cfs) and "b" (hrs) are divided by 24 to produce a fraction of a daily lag time.

YLAG, the percent of flow routed, is applied to the day-before flow at the upstream node as shown in Equation III-4 and is calculated using Equation III-5 as:

$$YLAG = (-0.0003/24)\ (1000) + 24/24 = 0.9875$$

where

1000 = the day-before flow at upstream node

Ninety-nine percent of the day-before flow at the upstream node is routed to the downstream node.

XLAG is calculated using Equation III-6 as:

$$XLAG = (-0.0003/24)(1500) + 24/24 = 0.9813$$

where

1500 = the present-day flow at upstream node.

Thus, the amount of the present-day upstream node flow routed to the downstream node is 1.87 percent or (1 - XLAG) as shown in Equation III-4.

The final calculation of the downstream node flow for the present-day, as computed by equation III-4, with no incremental runoff and a fraction of the day-before flow and a fraction of the present-day flow from the upstream node is:

$$FLOW(I) = 0 + 1000(0.9875) + 1500\ (1 - 0.9813) = 1015.55$$

Negative inflows are sometimes produced independent of the lag functions applied during the subtraction of recorded flows. These negative inflows could be the result of: inaccuracies in the recorded data (most gages record to $\pm$ 15 percent); small unaccountable diversions; or infiltration and evaporation between USGS stations (particularly on parts of the Schuylkill and Lehigh Rivers where the bedrock is limestone).

The models can handle negative inflows unless they produce abnormally low or negative flows when combined under regulated conditions. The only nodes which cannot readily accept negative inflows are those just downstream of an existing or proposed reservoir site. If such a node has a negative inflow, the negative inflow could produce a negative or abnormally low flow when only a conservation release is added from upstream under regulated conditions. The inflows to the nodes downstream of the existing and proposed reservoir sites are examined carefully for negative inflows. The nodes at which there are problems include:

Fishs Eddy,
Hale Eddy,
Lackawaxen at Honesdale
Oakland Valley,
Allentown, and
Tulpehocken at Reading.

The times during which negative inflows are a recurring problem for these gages are listed on Table III-3. During these times, the inflows are created in a different manner. The new methods of creating inflows for each troublesome node are also listed on Table III-3. For a node which has negative inflows during a regulated period (such as Hale Eddy), the new inflows to the node are calculated as a percentage of the unregulated inflow at an upstream station. The percentage is estimated using a drainage area ratio. For a node which has negative inflows during an unregulated period (such as Tulpehocken at Reading), new inflows are calculated for both the upstream and downstream nodes based on the recorded flow at the downstream gage.

After the inflows to the nodes downstream of reservoir sites are corrected for problems with recurring negatives, the inflows to those nodes downstream of reservoir sites are processed to remove any stray negatives. The remaining negative flows are made equal to zero and carried until the following day's positive inflows displace them. No more than three consecutive days of zeros occur with this process.

TABLE III-3

FIXES FOR RECURRING NEGATIVE INFLOWS
AT NODES DOWNSTREAM OF RESERVOIR NODES

Node	Dates	Method for New Inflows
Fishs Eddy	July 1964, October, 1964, October 1969	inflow = natural inflow to Pepacton x 0.526
Hale Eddy	September 1954, June 1961, July 1961, October 1963, July 1964, July 1966, September 1966, August 1966, June 1967, July 1968 to September 1977	inflow = natural inflow to Cannonsville x 0.3
Lackawaxen Honesdale	October 1944 to November 1945, April 1947, August-September 1950, June 1947, September 1952, September 1956, December 1958	inflow = flow at Lackawaxen at Honesdale x 0.242 (inflow to Prompton = flow at Lackawaxen x 0.3645, inflow to Dyberry at Honesdale = flow at Lackawaxen x 0.394)
	October 1965, April 1970, February 1971 to September 1977	inflow = Σ natural inflows to Prompton and Dyberry at Honesdale x 0.319
Oakland Valley	August-November 1943, November 1948, November 1950, July 1952, September 1959, January 1961, February 1961, October 1961, September 1962	inflow = natural inflow to Neversink x 0.586
Allentown	February 1966 - September 1977	inflow = flow at Allentown x 0.3 (inflow to Schnecksville = flow at Allentown x 0.7)
Tulpehocken at Reading	May 1965 - September 1977	inflow = flow at Tulpehocken at Reading x 0.17 (inflow to Blue Marsh = flow at Reading x 0.83)

This process is not applied to the inflows to the nodes on the Schuylkill at Reading and Lehigh at Walnutport. Negative inflows are allowed at these stations, because they are main stem stations and there is little danger of producing unusually low flows with the proposed relatively slight regulation.

After the final adjustments to the lag functions, the negative inflows which occur at the other nodes in the model are left intact. These negatives result from lagging and subtracting recorded data. By leaving these negatives in the input data, the recorded data are best preserved and continuity is maintained for flow.

RESULTS OF THE NATURAL FLOW MODEL

As in any modelling effort, the model which is to be used as a predictive tool has the ability to reconstitute recorded data. With this particular project, the shear volume of this data makes this type of comparison an arduous task. Since the USGS records prior to 1953 are not affected by regulation, the natural flow model simulation is compared to these records. Because of the amount of output generated by the model, this comparison is done in a two step process. First, to assure that continuity is preserved, the monthly average discharge for each of the simulated stations is compared to the data presented in the various USGS Surface Water Supply Records publications. As an example, recorded flows and simulated flows are presented in Figures III-8 through III-10. Figure III-8 gives the monthly mean discharge for water years 1951 through 1960 for the East Branch Delaware River at Fishs Eddy as presented in the U.S. Geological Survey Water Supply Paper 1722. Figures III-9 and III-10 present the model flows at Fishs Eddy for 1953 and 1954, respectively. The monthly mean flows are shown at the bottom of the daily flow table. A comparison of the monthly mean flows for 1953 and 1954 show that the simulated flows match the recorded flows when rounded to three significant figures. Note that in months subsequent to September 1954 the USGS records of Fishs Eddy do not agree with the simulated records. This, of course, is because the simulated records have eliminated the effect of the Pepacton Reservoir which became operational at that time.

DELAWARE RIVER BASIN

4210. East Branch Delaware River at Fishs Eddy, N. Y.

Location.--Lat 41°58'00", long 75°10'50", on left bank at downstream side of highway (revised) bridge at Fishs Eddy, Delaware County, just upstream from Fish Creek, 4½ miles downstream from Beaver Kill and 11 miles upstream from confluence of East and West Branches near Hancock.

Drainage area.--783 sq mi.

Records available.--October 1912 to September 1960. Monthly discharge only for some periods, published in WSP 1302.

Gage.--Water-stage recorder. Datum of gage is 950.96 ft above mean sea level, datum of 1929. Prior to Sept. 27, 1928, staff gage at same site and datum.

Extremes.--1912-60: Maximum discharge, 53,300 cfs Aug. 24, 1933 (gage height, 20.60 ft), from rating curve extended above 22,000 cfs by logarithmic plotting; minimum, 67 cfs Aug. 28, 1949; minimum gage height, 1.51 ft Aug. 4, 5, 1936.
Flood of Oct. 9, 1903, reached a stage of 23.6 ft, from descriptions obtained in April 1939 from local residents who had experienced the flood (discharge, about 70,000 cfs, from rating curve extended above 22,000 cfs by logarithmic plotting).

Remarks.--Subsequent to September 1954, entire flow from 371 sq mi of drainage area controlled by Pepacton Reservoir. Part of flow diverted for municipal supply of city of New York. Remainder of flow (except for conservation releases and spill) impounded for release during periods of low flow in the lower Delaware River basin, as directed by the Delaware River Master. Records of chemical analyses for the period October 1957 to September 1959 are published in reports of the Geological Survey.

Monthly and yearly mean discharge, in cubic feet per second

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1951	289	2,766	3,243	2,330	3,269	3,676	3,718	818	571	956	549	501	1,879
1952	1,139	3,664	2,621	2,905	2,038	2,998	4,509	2,407	1,331	1,090	316	630	2,133
1953	209	1,041	3,240	2,690	2,485	3,737	3,354	2,915	624	270	127	277	1,746
1954	322	1,060	2,741	1,271	2,927	2,308	2,371	2,572	659	190	113	224	1,397
1955	180	1,242	1,117	673	709	2,053	1,575	492	533	468	1,707	560	944
1956	2,531	1,738	652	803	828	1,560	4,951	2,242	1,241	831	867	735	1,579
1957	820	863	1,262	872	639	1,167	1,884	856	482	786	[illegible]	600	914
1958	546	695	2,465	831	405	758	3,526	1,791	603	595	763	797	1,152
1959	959	1,303	710	1,009	748	1,239	2,570	690	736	799	767	833	1,034
1960	1,632	2,316	1,930	1,104	1,306	696	4,395	874	1,271	450	319	1,639	1,502

Monthly and yearly runoff, in inches

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1951	0.42	3.94	4.77	3.43	4.35	5.41	5.30	1.21	0.81	1.41	0.81	0.71	32.57
1952	1.68	5.22	3.86	4.28	2.81	4.41	6.42	3.54	1.90	1.61	.47	.90	37.10
1953	.31	1.48	4.77	3.96	3.31	5.50	4.78	4.29	.89	.40	.19	.39	30.27
1954	.47	1.51	4.04	1.87	3.89	3.40	3.38	3.79	.94	.28	.17	-	-

Yearly discharge, in cubic feet per second

Year	WSP	Water year ending Sept. 30							Calendar year	
		Momentary maximum		Minimum day	Mean	Per square mile	Runoff in inches		Mean	Runoff in inches
		Discharge	Date							
1950	-	-	-	-	-	-	-		1,948	33.76
1951	1202	43,000	Mar. 31, 1951	233	1,879	2.40	32.57		1,972	34.20
1952	1232	20,000	Apr. 6, 1952	192	2,133	2.72	37.10		1,832	32.93
1953	1272	38,400	Dec. 11, 1952	75	1,746	2.23	30.27		1,715	29.73
1954	1332	12,200	Feb. 17, 1954	73	1,397	-	-		1,252	-
1955	1382	27,400	Aug. 19, 1955	81	944	-	-		1,145	-
1956	1432	17,600	Oct. 16, 1955	403	1,579	-	-		1,414	-
1957	1502	8,270	Apr. 6, 1957	190	914	-	-		980	-
1958	1552	36,600	Dec. 21, 1957	208	1,152	-	-		1,033	-
1959	1622	17,600	Apr. 3, 1959	210	1,034	-	-		1,278	-
1960	1702	23,800	Apr. 5, 1960	168	1,502	-	-		-	-

FIGURE III-8. Monthly Mean Discharges at East Branch Delaware River at Fishs Eddy as Reported by the U.S.G.S.

CDM/ WATER RESOURCES ENGINEERS
SPRINGFIELD, VIRGINIA
NODE 2010

* * * * P H A S E 2 * * * *
DELAWARE RIVER

NATURAL FLOW SIMULATION
OCTOBER 6,1979
FLOW DELAWARE AT FISHS EDDY 014210

DISCHARGE SIMULATED FOR 1955 (CFS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	819.93	3000.77	1750.25	3743.43	5297.47	1049.49	539.23	139.99	91.33	126.39	1097.18	1433.65
2	760.14	2149.68	1400.32	3689.34	5310.46	939.81	492.27	139.33	79.67	121.99	885.99	1299.94
3	760.09	2000.36	1359.21	3329.70	5339.21	839.00	399.95	136.99	76.67	113.99	759.25	1159.41
4	719.59	1800.15	2299.65	2923.49	4983.47	774.57	340.99	135.33	74.67	110.66	647.27	1039.75
5	619.51	1550.12	3029.95	2813.81	4730.21	906.41	301.59	136.66	79.67	111.39	570.72	1320.21
6	530.17	1500.48	1999.79	2430.15	4353.15	749.39	293.96	139.66	117.03	154.23	520.09	1599.70
7	519.59	2739.89	1750.29	4399.35	4240.05	1120.21	295.39	135.33	879.09	391.34	493.48	7879.57
8	547.46	3619.78	1530.34	4790.31	4310.14	957.69	299.64	132.99	921.12	469.39	509.37	7460.18
9	550.47	2503.31	1359.35	3799.77	4050.03	779.98	377.66	131.90	441.59	383.31	499.09	5070.12
10	730.02	2000.30	1250.16	3700.28	3529.53	667.39	438.45	139.01	299.39	327.50	498.83	5569.96
11	1479.51	1650.13	1119.57	3699.72	3370.24	598.54	347.53	140.67	227.53	289.57	547.95	5623.67
12	1299.53	1700.30	1220.21	3100.41	2659.31	544.12	206.88	137.33	196.27	263.60	555.81	4260.27
13	1140.41	1549.85	1379.65	3099.35	2983.72	575.46	257.61	139.99	763.37	244.28	570.63	3983.35
14	1019.94	1400.31	2469.73	3333.03	3389.33	653.24	250.09	129.38	598.41	230.94	538.23	3789.57
15	979.79	1400.30	3150.21	2739.80	2179.77	571.31	239.69	242.96	451.89	216.29	598.18	4599.77
16	1050.11	1399.78	8610.25	2770.40	2253.47	501.07	225.69	218.90	375.37	203.31	598.08	3600.27
17	1450.36	1299.75	6089.72	3043.00	2730.32	454.47	207.63	168.99	320.89	192.97	675.51	2699.94
18	1999.76	1150.44	4530.23	2739.51	3019.76	417.86	192.97	138.75	275.07	198.31	693.79	2049.90
19	3130.38	1079.96	4219.51	2789.34	2560.35	395.26	196.00	124.63	249.89	178.99	715.86	1909.43
20	2490.01	1099.93	4199.55	2740.17	2239.57	379.24	222.73	118.32	225.93	170.65	713.07	1850.45
21	2259.74	5499.90	3449.73	2560.37	1310.17	351.61	234.39	110.56	278.31	168.99	730.14	1809.47
22	2049.64	7559.69	3040.17	2330.43	1597.32	397.76	239.59	107.32	171.29	161.99	699.21	1750.79
23	1870.26	4959.64	2889.81	2120.32	2560.15	370.43	199.69	104.33	176.37	159.66	1940.11	1590.92
24	9249.31	3920.04	5699.22	2013.38	2330.17	319.85	231.09	99.33	162.31	162.33	2670.09	1399.75
25	16320.37	3360.18	7949.75	1979.06	1510.23	291.26	213.31	95.33	153.98	162.33	2320.57	1169.23
26	8679.86	2860.32	8420.38	3370.39	1497.07	296.00	292.62	91.99	144.65	159.67	2330.34	1200.24
27	5430.20	2569.67	8180.29	6840.21	1710.05	374.21	180.78	90.33	141.09	162.30	2409.57	1099.76
28	4899.54	2260.04	6999.54	5870.44	1489.87	359.27	166.65	86.79	137.33	359.50	2079.84	1020.37
29	4199.43	0.00	5489.71	4599.57	1220.93	1177.31	155.65	85.67	133.32	798.96	1839.91	967.18
30	3100.21	0.00	4639.91	3769.06	1139.37	1049.06	154.00	82.99	126.65	1599.74	1580.02	917.56
31	2699.93	0.00	4419.02	0.00	1210.33	0.00	145.00	80.67	0.00	1949.92	0.00	799.92
MIN	519.59	1079.76	1119.57	1970.06	1133.97	296.00	145.00	80.67	74.67	110.66	470.49	799.92
MAX	16320.39	7559.69	8610.25	6840.21	5310.46	1170.31	539.23	242.96	921.12	1699.74	2730.34	7879.57
MEAN	2670.29	2485.39	3736.74	3354.[illegible]	2713.23	624.59	257.57	127.38	276.69	322.11	1057.36	2741.15
TOTAL	83378.94	69590.78	115839.07	10[illegible]	[illegible]	19737.79	9337.26	3748.92	8370.37	9795.37	31810.87	84975.74
S DEV	3322.49	1479.31	2355.32	[illegible]	[illegible]	255.57	106.87	34.99	229.07	358.22	749.59	2206.19

...ted Natural Discharge 1955 ...
...ugh Delaware River at Fishs E...

CDM/ WATER RESOURCES ENGINEERS
SPRINGFIELD, VIRGINIA
NODE 2019

* * * * P H A S E 2 * * * *
DELAWARE RIVER

NATURAL FLOW SIMULATION
OCTOBER 6,1979
E BR DELAWARE AT FISHS EDDY 01421000

AVERAGE DAILY DISCHARGE SIMULATED FOR 1954 (CFS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	579.83	1999.98	2550.31	1739.68	2153.35	1920.42	337.73	118.38	762.03	250.37	712.87	1955.76
2	620.00	1900.05	5930.29	1629.69	2133.33	1299.71	313.68	114.32	491.51	256.43	892.65	1743.33
3	740.04	1800.02	4370.04	1500.15	1737.33	1229.75	298.86	123.00	319.61	277.80	6799.97	1577.08
4	680.46	1600.15	4463.51	1350.26	4297.21	1130.36	280.93	140.01	242.65	272.40	7395.65	1402.31
5	630.00	1399.71	3200.27	1297.54	3563.76	1040.16	258.94	136.02	204.83	242.88	5143.17	1316.38
6	599.51	1250.26	2697.83	1297.82	2951.65	945.97	252.94	129.54	181.25	229.93	3818.92	1110.35
7	540.03	1099.62	2349.57	1670.44	2519.53	889.19	244.54	119.32	169.61	219.39	2969.54	373.40
8	399.79	979.80	2200.30	1609.97	2759.92	794.15	236.97	109.99	175.39	210.62	2469.51	993.28
9	370.13	960.41	1949.71	1559.37	3170.59	715.10	227.32	104.99	185.02	203.32	2181.65	1031.25
10	457.56	899.68	1949.8	1487.97	4551.18	648.54	216.97	102.66	188.36	202.68	1935.79	1057.68
11	470.32	859.88	1759.33	1323.73	6243.65	615.39	200.63	108.38	174.39	203.68	1636.35	1007.82
12	460.44	639.71	1550.03	1789.84	4839.63	561.73	187.65	105.30	387.37	200.62	1556.61	913.48
13	440.12	540.57	1449.95	1697.61	3359.58	833.45	191.31	103.30	393.50	191.52	1424.97	845.57
14	419.57	719.45	1549.67	1559.53	3270.17	997.68	170.31	100.66	298.73	183.95	1294.19	988.40
15	479.87	850.72	1759.75	1519.78	2760.05	693.11	165.66	102.66	249.65	189.81	1203.98	2560.29
16	450.06	1799.98	1500.07	1499.91	2389.77	586.45	160.35	103.33	192.36	626.98	1132.71	2679.36
17	460.42	9109.75	1430.03	7299.35	2093.77	534.68	159.66	97.56	360.31	1010.77	1071.10	1929.97
18	470.00	9023.58	1349.51	6759.56	1962.36	483.44	158.31	94.70	673.48	690.58	1047.42	3411.41
19	449.58	5529.90	1300.16	4680.22	1669.72	438.46	157.97	90.39	523.35	685.29	1335.29	5025.00
20	500.07	4089.68	2100.44	3689.73	1559.23	409.16	152.33	88.33	531.37	868.93	1117.48	4535.36
21	1500.05	4029.54	2600.41	3100.44	1590.14	368.20	153.70	83.66	474.47	983.24	3827.59	3241.64
22	2599.73	8490.06	2189.75	2579.55	2399.97	348.29	164.48	79.56	450.90	906.35	5250.65	2593.31
23	1399.95	5640.20	2099.77	2517.72	2230.87	357.65	172.57	75.57	441.08	838.59	3868.33	2318.98
24	1243.01	4199.69	1953.23	2430.36	1959.59	434.38	153.61	72.67	392.27	777.34	3179.26	2131.49
25	1240.00	3929.73	1930.04	2150.07	1763.73	369.50	144.01	88.56	355.73	719.53	2737.45	1909.41
26	1209.95	3260.37	2659.51	2000.19	1630.49	330.18	140.31	180.68	328.17	668.35	2471.76	1483.92
27	4700.23	2870.34	2429.53	2041.17	1473.53	320.32	134.32	142.20	319.59	644.54	2152.55	1429.03
28	6000.39	2469.75	2230.33	1589.99	1379.64	319.68	128.93	120.52	294.87	623.10	1951.47	1391.07
29	3699.75	0.00	2170.28	2610.12	1347.48	320.29	126.99	111.98	278.51	719.41	2194.78	2516.95
30	3210.38	0.00	2049.51	2319.25	2129.54	310.58	122.65	106.79	259.21	712.77	2255.02	3978.26
31	2450.42	0.00	1879.97	0.00	1733.22	0.00	117.03	234.71	0.00	743.91	0.00	3759.34
MIN	370.13	540.57	1300.16	1299.54	1340.49	310.58	117.03	72.67	159.61	183.95	712.87	845.57
MAX	6000.39	9109.75	5930.29	7099.35	6243.65	1920.42	313.69	234.71	762.03	1010.77	7395.65	5125.00
MEAN	1271.31	2926.74	2307.72	2371.27	2571.9	557.92	170.12	112.59	341.32	504.13	2560.99	2086.63
TOTAL	39410.54	81948.67	71539.72	71137.98	79728.92	16737.67	5273.87	3499.97	10239.57	15624.96	76829.51	64685.58
S DEV	1378.88	2513.67	985.91	1424.15	1127.25	323.83	56.95	31.13	142.80	285.70	1689.36	1219.38

FIGURE III-10. Simulated Natural Discharge 1954: East Branch Delaware River at Fishs Eddy

After demonstrating that continuity is preserved on a monthly basis for each of the sixty stations, the simulated daily flows are compared to assure their validity. Figures III-11 through III-17 show typical comparisons of the simulated daily data to data recorded by the USGS. Figure III-11 presents recorded flows of various stations for the first eight days of January 1953. Six gaging stations are underlined in the figure for which simulated flows are presented in Figures III-12 through III-17, respectively. For example, the flows of 1-8 January 1953 for the first station underlined (01417000) in Figure III-11 compare favorably to the first eight days of January for this station, E. Branch Delaware River at Downsville, in Figure III-12. The simulated daily data satisfactorily match the unregulated daily records of the USGS. Variations between the simulated and recorded data is attributed to round-off applied during the procedures used to develop the total flow at the gage locations.

Duration and Frequency Analysis

The natural flow model for the Delaware River Basin simulates the natural daily flows for a 50-year base period from water year 1928 through water year 1977, a flow duration and low flow frequency analysis is performed on the 50 years of naturalized flows for the following 44 key locations:

1. East Branch Delaware River at Downsville, N.Y.,
2. East Branch Delaware River at Fishs Eddy, N.Y.,
3. West Branch Delaware River at Stilesville, N.Y.,
4. West Branch Delaware River at Hale Eddy, N.Y.,
5. Delaware River near Callicoon, N.Y.,
6. Delaware River near Barryville, N.Y.,
7. West Branch Lackawaxen River at Prompton, PA,
8. Dyberry Creek near Honesdale, PA,
9. Lackawaxen River at Honesdale, PA,
10. Lackawaxen River at Hawley, PA,
11. Delaware River at Port Jervis, N.Y.,
12. Neversink River at Neversink, N.Y.,

Flows for 1-8 January 1953

```
3    0141350019530101 125.00 120.00 125.00 120.00 114.00 102.00  92.00  96.00
3    0141700019530101 353.00 325.00 325.00 321.00 271.00 260.00 230.00 240.00
3    0142100019530101 820.00 760.00 760.00 720.00 620.00 560.00 520.00 540.00
3    0142300019530101 320.00 301.00 307.00 291.00 235.00 215.00 185.00 205.00
3    0142500019530101 440.00 420.00 420.00 410.00 340.00 300.00 270.00 280.00
3    0142650019530101 540.00 500.00 520.00 500.00 400.00 350.00 320.00 330.00
3    01428500195301012000.001850.001800.001800.001600.001400.001300.001250.00
3    0142900019530101  56.00  51.00  52.00  51.00  44.00  42.00  41.00  44.00
3    0142950019530101  49.00  45.00  43.00  41.00  36.00  43.00  45.00  44.00
3    0143000019530101 160.00 150.00 145.00 150.00 130.00 125.00 145.00 145.00
3    0143150019530101 270.00 250.00 235.00 250.00 205.00 190.00 205.00 208.00
3    0143200019530101      0  86.00      0      0 523.00 395.00 227.00 678.00
3    0143350019530101 466.00 542.00 474.00 333.00 488.00 439.00 446.00 446.00
3    01434000195301013810.003540.003590.003350.003100.003080.002770.002820.00
3    0143500019530101  98.00  94.00  96.00  84.00  72.00  68.00  66.00  66.00
3    0143600019530101 140.00 130.00 135.00 116.00 100.00  94.00  90.00  90.00
3    0143700019530101 320.00 300.00 314.00 290.00 250.00 230.00 220.00 220.00
3    01438500195301014830.004430.004500.004290.004120.004120.003680.003460.00
3    01446500195301017000.006300.006370.006440.005970.005730.005370.005010.00
3    0144750019530101 150.00 146.00 146.00 144.00 128.00 119.00 124.00 122.00
3    0144800019530101 508.00 484.00 490.00 490.00 448.00 436.00 402.00 414.00
3    0145000019530101 203.00 194.00 200.00 191.00 172.00 158.00 155.00 158.00
3    0145050019530101 132.00 124.00 132.00 121.00 111.00 103.00  99.00 103.00
3    01451000195301011550.001480.001510.001480.001350.001260.001220.001240.00
3    0145200019530101  92.00  85.00  92.00  95.00  82.00  69.00  66.00  66.00
3    01453000195301012360.002280.002300.002320.002120.001930.001860.001910.00
3    0145600019530101 217.00 217.00 248.00 248.00 237.00 232.00 222.00 212.00
3    0145700019530101 357.00 353.00 411.00 407.00 376.00 353.00 346.00 346.00
3    0145750019530101 10500.9760.009610.009900.009150.008540.008130.007790.00
3    0145950019530101  46.00  44.00 108.00 170.00 105.00  70.00  54.00  56.00
3    0146050019530101  26.00  26.00  26.00  27.00  27.00  28.00  28.00  27.00
3    0146350019530101 10900. 10300. 10200. 10900. 10000.9250.008870.008560.00
3    0146400019530101  89.00  92.00 184.00 193.00 179.00 160.00 133.00 128.00
3    0146450019530101 133.00 130.00 248.00 263.00 172.00 148.00 133.00 136.00
3    0146550019530101 174.00 169.00 324.00 515.00 280.00 230.00 208.00 215.00
3    0146700019530101 143.00 173.00 223.00 256.00 250.00 223.00 213.00 213.00
3    0146950019530101  63.00  58.00  66.00  65.00  58.00  50.00  49.00  49.00
3    0147100019530101 317.00 308.00 348.00 332.00 298.00 270.00 270.00 280.00
3    01472000195301011750.001700.001800.001860.001650.001550.001450.001550.00
3    0147300019530101 220.00 215.00 322.00 511.00 314.00 248.00 222.00 232.00
3    01474500195301012320.002110.002460.003120.002610.002220.001980.002030.00
3    0147700019530101  83.00  79.00 139.00 104.00  84.00  77.00  74.00  91.00
3    0147900019530101 102.00  95.00 144.00 149.00 108.00  97.00  95.00 131.00
3    0148000019530101  66.00  60.00  76.00  76.00  63.00  58.00  60.00  76.00
3    0148150019530101 428.00 415.00 508.00 560.00 469.00 422.00 415.00 445.00
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FIGURE III-11. Record U.S.G.S. Data for
January 1 - January 8, 1953

CDM/ WATER RESOURCES ENGINEERS
SPRINGFIELD, VIRGINIA
NODE 2010

* * * * D H A D E Z * * * *
* DELAWARE RIVER *

NATURAL FLOW SIMULATION
OCTOBER 4,1979
E BR DELAWARE AT DOWNSVILLE 01417000

AVERAGE DAILY DISCHARGE SIMULATED FOR 1953 (CFS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	353.00	1250.00	746.00	1630.00	2340.00	421.00	195.00	58.00	23.00	50.00	535.00	737.00
2	325.00	880.00	595.00	1700.00	2710.00	357.00	156.00	56.00	24.00	47.00	445.00	634.00
3	325.00	860.00	560.00	1450.00	2270.00	333.00	139.00	53.00	23.00	44.00	395.00	556.00
4	321.00	760.00	389.00	1300.00	1970.00	309.00	123.00	51.00	22.00	43.00	332.00	514.00
5	271.00	680.00	1030.00	1260.00	2140.00	311.00	110.00	50.00	24.00	43.00	297.00	689.00
6	266.00	600.00	774.00	1100.00	1730.00	277.00	134.00	47.00	42.00	100.00	250.00	797.00
7	230.00	1360.00	700.00	1500.00	1580.00	454.00	119.00	47.00	675.00	241.00	270.00	1550.00
8	240.00	1430.00	539.00	1760.00	1530.00	375.00	115.00	44.00	305.00	206.00	258.00	3310.00
9	250.00	1020.00	580.00	1443.00	1650.00	305.00	159.00	44.00	165.00	165.00	258.00	2320.00
10	333.00	881.00	520.00	1380.00	1450.00	266.00	171.00	47.00	112.00	146.00	279.00	2870.00
11	645.00	760.00	463.00	1350.00	1240.00	233.00	125.00	47.00	77.00	133.00	316.00	2330.00
12	540.00	790.00	547.00	1145.00	1190.00	215.00	129.00	47.00	89.00	123.00	324.00	1800.00
13	472.00	715.00	628.00	1160.00	1190.00	226.00	98.00	44.00	490.00	115.00	310.00	1690.00
14	437.00	645.00	841.00	1240.00	1050.00	244.00	78.00	125.00	320.00	106.00	352.00	1590.00
15	421.00	645.00	920.00	1020.00	980.00	216.00	109.00	186.00	237.00	98.00	344.00	1950.00
16	620.00	620.00	2470.00	1100.00	1130.00	193.00	87.00	109.00	183.00	93.00	381.00	1400.00
17	760.00	562.00	2180.00	1100.00	1240.00	174.00	90.00	90.00	162.00	87.00	433.00	1130.00
18	1230.00	486.00	1670.00	1030.00	1220.00	157.00	74.00	68.00	130.00	82.00	438.00	821.00
19	1470.00	472.00	1510.00	1110.00	1182.00	151.00	74.00	58.00	112.00	77.00	446.00	830.00
20	1130.00	494.00	1590.00	1080.00	774.00	140.00	88.00	53.00	100.00	75.00	446.00	780.00
21	1020.00	2770.00	1250.00	1030.00	860.00	133.00	78.00	47.00	95.00	72.00	438.00	760.00
22	928.00	3000.00	1100.00	929.00	757.00	159.00	92.00	44.00	87.00	53.00	433.00	753.00
23	809.00	2610.00	1000.00	961.00	775.00	140.00	87.00	42.00	79.00	68.00	1330.00	720.00
24	4010.00	1600.00	1630.00	941.00	637.00	119.00	87.00	40.00	74.00	56.00	1340.00	560.00
25	7490.00	1360.00	2710.00	828.00	559.00	108.00	82.00	38.00	68.00	54.00	1250.00	530.00
26	3800.00	1190.00	3630.00	1230.00	525.00	108.00	72.00	35.00	64.00	56.00	1490.00	520.00
27	2400.00	1030.00	3830.00	2510.00	732.00	138.00	66.00	33.00	64.00	55.00	1170.00	530.00
28	2250.00	914.00	3100.00	2310.00	395.00	130.00	62.00	30.00	52.00	185.00	1020.00	455.00
29	1790.00	0.00	2450.00	1830.00	414.00	468.00	58.00	27.00	57.00	323.00	883.00	446.00
30	1250.00	0.00	2080.00	1470.00	455.00	319.00	58.00	26.00	53.00	752.00	772.00	428.00
31	1170.00	0.00	2060.00	0.00	414.00	0.00	59.00	25.00	0.00	675.00	0.00	393.00
MIN	230.00	472.00	469.00	828.00	455.00	108.00	58.00	25.00	22.00	43.00	250.00	380.00
MAX	7490.00	3000.00	3830.00	2510.00	2710.00	468.00	195.00	186.00	675.00	953.00	1490.00	3550.00
MEAN	1210.42	1061.73	1448.1	1322.33	1204.1	241.13	101.06	54.97	136.17	151.93	575.1	1213.74
TOTAL	37523.00	29734.00	44893.0	39698.00	37327.0	7234.00	3133.00	1704.00	4085.00	4709.00	17253.00	37316.00
S_DEV	1409.19	525.32	939.	391.51	596.48	105.47	34.02	31.48	146.82	190.82	375.42	981.19

FIGURE III-12. Simulated Natural Flow 1953: East Branch Delaware River at Downsville

CDM/ WATER RESOURCES ENGINEERS
SPRINGFIELD, VIRGINIA
NODE 2010

. . . . . P H A S E 2 . . . . .
DELAWARE RIVER

NATURAL FLOW SIMULATION
OCTOBER 6, 1977
E BR DELAWARE AT FISHS EDDY 01421000

---AVERAGE DAILY DISCHARGE SIMULATED FOR 1953 (CFS)---

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	819.93	3000.17	1730.22	3740.40	5240.47	1040.80	639.23	132.99	91.33	126.97	1090.18	1437.65
2	760.14	2149.68	1400.32	3689.44	5910.46	939.81	492.27	139.33	77.67	121.99	885.90	1299.94
3	760.09	2000.36	1350.21	3329.70	5300.21	838.00	399.85	136.99	76.67	113.99	750.25	1150.41
4	719.53	1800.15	2299.60	2920.49	4990.47	774.57	340.83	135.33	74.67	110.66	647.27	1039.75
5	619.51	1550.12	3029.92	2810.91	4730.21	906.43	301.59	136.66	79.67	111.00	570.72	1320.21
6	560.17	1590.48	1999.70	2490.13	4950.15	799.39	233.96	139.66	117.03	154.23	530.09	1599.70
7	519.59	2739.89	1750.27	4300.35	4240.05	1130.21	296.39	135.33	870.09	441.34	470.48	3879.57
8	540.46	3619.78	1530.39	4700.31	4310.14	757.69	299.64	132.99	921.17	469.93	538.30	7460.18
9	560.47	2500.31	1250.33	3739.77	4050.00	779.98	377.66	131.00	441.50	383.91	499.00	5070.12
10	730.02	2000.30	1250.16	3700.28	3529.53	667.39	438.45	139.01	299.39	327.59	498.83	5569.96
11	1479.51	1650.13	1119.59	3699.72	3370.24	598.54	347.63	140.67	227.55	289.57	547.95	5629.67
12	1299.53	1700.30	1220.21	3100.41	2650.31	549.12	296.88	137.33	196.27	263.60	555.81	4260.27
13	1140.41	1549.85	1379.65	3099.95	2483.72	575.46	257.61	139.99	763.37	244.28	579.63	3989.35
14	1019.94	1400.01	2469.73	3330.52	2389.53	653.24	250.00	129.38	598.41	230.34	538.23	3789.57
15	979.79	1400.30	3150.21	2739.80	2179.77	571.31	239.68	242.96	451.98	216.29	598.18	4599.77
16	1080.11	1399.78	8610.25	2770.90	2250.47	501.07	225.60	218.00	375.37	203.31	598.08	3600.27
17	1450.05	1299.75	6089.72	3060.00	2790.33	454.47	207.63	168.98	320.80	192.97	675.51	2699.94
18	1999.76	1150.44	4530.23	2739.51	3310.96	417.86	172.97	138.95	275.07	188.31	693.79	2049.80
19	3130.38	1079.96	4219.31	2780.44	2360.35	395.26	136.00	124.63	249.88	178.99	726.86	1900.43
20	2490.01	1099.93	4199.55	2740.17	2239.59	370.24	222.73	118.32	225.93	170.65	713.00	1850.45
21	2259.74	5499.90	3449.73	2560.39	1910.17	351.61	234.37	110.66	278.31	168.99	730.14	1800.47
22	2049.64	7559.69	3080.17	2330.43	1540.32	393.96	239.59	107.32	131.29	161.39	699.21	1750.00
23	1820.26	4959.64	2989.81	2120.32	2560.15	370.43	199.69	104.33	176.33	159.66	1940.11	1680.02
24	9280.31	3920.04	5699.22	2010.38	2000.19	317.85	231.00	99.33	162.31	162.33	2670.09	1399.95
25	16320.39	3360.18	7949.73	1970.76	1510.03	291.26	213.31	95.33	153.98	162.33	2320.53	1160.23
26	8679.86	2860.32	8420.38	3370.38	1490.09	296.00	292.62	91.99	144.65	159.67	2930.34	1200.24
27	5400.20	2569.67	8180.29	6840.21	1710.05	374.21	190.78	90.33	141.03	152.30	2439.59	1099.76
28	4899.54	2260.04	6999.59	5870.44	1490.83	350.27	166.65	86.99	137.33	359.50	2079.94	1020.39
29	4199.83	0.00	5489.71	4597.57	1220.93	1170.31	135.65	85.67	133.32	798.96	1809.91	967.19
30	3100.21	0.00	4639.91	3769.96	1139.97	1040.06	154.00	80.99	126.65	1599.74	1580.02	907.56
31	2699.93	0.00	4410.02	0.00	1210.93	0.00	145.00	80.57	0.00	1449.82	0.00	799.92
MIN	519.59	1079.76	1119.59	1970.76	1133.97	286.00	145.00	80.57	74.57	110.66	470.48	799.92
MAX	16320.39	7559.69	8610.25	6840.21	5910.45	1170.31	639.23	242.96	921.12	1599.74	2930.34	3879.57
MEAN	2690.29	2485.39	3736.74	3354.44	2315.23	624.59	269.59	127.38	276.68	322.11	1050.36	2741.15
TOTAL	83398.94	69590.78	115833.07	100633.23	70372.19	18737.70	8337.26	3948.92	8300.33	9985.40	31810.87	84975.74
S DEV	3302.49	1479.31	2355.32	1055.12	1354.67	255.57	126.83	34.99	229.09	358.22	749.59	2206.19

FIGURE III-13. Simulated Natural Flow 1953: East Branch Delaware Riber at Fishs Eddy

CDM/ WATER RESOURCES ENGINEERS
SPRINGFIELD, VIRGINIA
NODE 2020

* * * * P H A S E 2 * * * *
DELAWARE RIVER

NATURAL FLOW SIMULATION
OCTOBER 6,1979
W BR DELAWARE AT STILESVILLE 01425000

AVERAGE DAILY DISCHARGE SIMULATED FOR 1953 (CFS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	445.00	1550.00	880.00	2150.00	2590.00	518.00	135.00	55.00	42.00	66.00	339.00	739.00
2	420.00	1000.00	660.00	2050.00	3340.00	429.00	160.00	56.00	42.00	62.00	302.00	653.00
3	420.00	1020.00	640.00	1740.00	2730.00	379.00	145.00	54.00	40.00	58.00	275.00	572.00
4	410.00	960.00	960.00	1490.00	2270.00	333.00	135.00	52.00	38.00	54.00	259.00	521.00
5	340.00	740.00	1240.00	1480.00	2390.00	344.00	120.00	54.00	54.00	59.00	235.00	616.00
6	320.00	760.00	850.00	1280.00	2340.00	335.00	110.00	52.00	134.00	130.00	210.00	723.00
7	270.00	1380.00	760.00	2370.00	1980.00	371.00	106.00	47.00	691.00	430.00	210.00	1310.00
8	280.00	1880.00	660.00	2630.00	1720.00	313.00	106.00	44.00	897.00	390.00	216.00	3270.00
9	340.00	1210.00	620.00	2080.00	1930.00	272.00	130.00	44.00	387.00	260.00	220.00	2410.00
10	540.00	1040.00	620.00	1980.00	1520.00	235.00	120.00	47.00	259.00	205.00	239.00	2770.00
11	1300.00	900.00	500.00	1850.00	1270.00	217.00	110.00	50.00	202.00	190.00	259.00	2290.00
12	860.00	940.00	579.00	1480.00	1110.00	195.00	100.00	50.00	167.00	165.00	275.00	1740.00
13	700.00	869.00	738.00	1480.00	1420.00	205.00	92.00	49.00	164.00	155.00	275.00	1700.00
14	640.00	777.00	921.00	1560.00	1380.00	215.00	88.00	752.00	270.00	145.00	296.00	1590.00
15	580.00	787.00	942.00	1280.00	1240.00	195.00	84.00	620.00	190.00	130.00	296.00	2220.00
16	1000.00	740.00	1470.00	1260.00	1440.00	165.00	90.00	310.00	155.00	122.00	291.00	1610.00
17	1430.00	680.00	1520.00	1260.00	1710.00	150.00	76.00	205.00	140.00	116.00	330.00	1300.00
18	1640.00	580.00	1330.00	1160.00	1710.00	140.00	70.00	155.00	124.00	110.00	321.00	1040.00
19	2170.00	560.00	1440.00	1260.00	1420.00	130.00	68.00	125.00	118.00	102.00	302.00	950.00
20	1580.00	596.00	1650.00	1250.00	1240.00	125.00	70.00	108.00	114.00	98.00	291.00	980.00
21	1420.00	3700.00	1340.00	1230.00	1060.00	120.00	68.00	94.00	110.00	94.00	286.00	975.00
22	1250.00	4040.00	1190.00	1130.00	942.00	130.00	64.00	86.00	104.00	92.00	275.00	975.00
23	1110.00	2400.00	1090.00	1040.00	1030.00	110.00	72.00	76.00	100.00	88.00	850.00	964.00
24	4340.00	2020.00	1570.00	985.00	900.00	102.00	122.00	70.00	94.00	86.00	1270.00	740.00
25	7730.00	1760.00	2540.00	932.00	737.00	95.00	100.00	54.00	90.00	86.00	979.00	620.00
26	4100.00	1450.00	3470.00	1060.00	661.00	140.00	80.00	60.00	98.00	92.00	1460.00	640.00
27	2530.00	1330.00	3880.00	2300.00	867.00	200.00	72.00	55.00	86.00	92.00	1130.00	598.00
28	2600.00	1170.00	3600.00	2130.00	728.00	120.00	68.00	52.00	80.00	100.00	985.00	538.00
29	2100.00	0.00	2870.00	1820.00	596.00	480.00	64.00	48.00	76.00	142.00	869.00	504.00
30	1450.00	0.00	2410.00	1560.00	552.00	410.00	72.00	46.00	70.00	474.00	768.00	491.00
31	1370.00	0.00	2730.00	0.00	605.00	0.00	62.00	44.00	0.00	473.00	0.00	430.00
MIN	270.00	560.00	500.00	932.00	552.00	95.00	52.00	44.00	38.00	54.00	210.00	430.00
MAX	7730.00	4040.00	3880.00	2630.00	3340.00	518.00	195.00	752.00	897.00	474.00	1450.00	3310.00
MEAN	1458.06	1315.68	1473.55	1565.90	1465.23	239.30	97.06	116.77	170.20	155.97	477.07	1273.19
TOTAL	45200.00	36839.00	45680.00	46977.00	45422.00	7179.00	3009.00	3626.00	5106.00	4835.00	14312.00	39469.00
S DEV	1532.14	842.68	951.41	437.48	593.47	120.62	31.71	160.15	182.42	119.29	359.13	923.05

FIGURE III-14. Simulated Natural Flow 1953: West Branch Delaware River at Stilesville

CDM/ WATER RESOURCES ENGINEERS
SPRINGFIELD, VIRGINIA
NODE 2120

* * * * P H A S E 2 * * * *
DELAWARE RIVER

NATURAL FLOW SIMULATION
OCTOBER 6,1979
NEVERSINK R AT OAKLAND VALLEY 01437000

AVERAGE DAILY DISCHARGE SIMULATED FOR 1953 (CFS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	320.14	819.72	520.23	806.97	1500.39	378.06	91.35	47.24	25.00	48.00	205.73	229.18
2	350.41	640.17	439.74	878.93	1559.16	321.08	107.22	51.76	27.00	44.10	155.18	220.89
3	314.29	599.62	440.26	830.30	1383.29	207.02	100.48	57.50	27.50	42.75	132.70	207.93
4	290.09	549.32	932.68	698.27	1110.41	130.25	87.99	55.75	31.50	42.25	111.24	209.55
5	249.88	480.36	1110.09	685.30	1200.08	125.25	83.75	55.76	44.75	43.75	131.49	259.47
6	230.46	470.00	702.52	616.14	1340.27	117.50	93.25	58.00	75.11	58.52	94.99	398.87
7	219.98	760.21	579.97	1609.69	1079.51	197.25	89.01	55.99	101.02	88.07	107.04	1816.46
8	220.00	1020.47	490.38	1890.33	1080.45	169.00	85.73	50.50	86.42	95.45	123.27	1929.85
9	229.59	591.59	440.05	1179.63	1010.17	139.00	133.10	53.30	62.72	73.22	121.48	931.44
10	319.70	540.05	420.06	1110.38	877.38	115.75	107.17	74.14	59.74	59.39	117.49	1279.98
11	420.28	470.35	370.38	1299.71	771.78	100.25	86.23	73.98	46.25	50.24	117.01	1593.47
12	419.69	470.00	393.87	1010.14	677.03	91.00	79.75	60.49	47.75	43.30	124.00	923.45
13	339.74	450.04	754.28	1311.34	731.97	93.00	89.03	51.59	99.53	44.50	123.02	796.31
14	269.65	420.06	1409.69	1429.75	933.62	106.00	96.02	49.50	76.24	51.75	126.00	988.10
15	280.35	433.89	1559.91	1030.50	778.54	98.00	87.97	49.75	59.49	52.30	119.98	1139.65
16	289.88	521.42	4759.56	1033.02	778.85	82.25	76.23	45.50	51.99	48.75	121.34	883.87
17	320.26	468.38	2129.53	1063.49	873.77	71.75	68.23	43.00	59.75	52.30	142.89	560.19
18	469.61	380.08	1310.67	874.28	1080.35	66.00	62.00	43.75	48.00	51.30	164.44	529.43
19	741.55	370.00	1250.21	958.31	828.83	63.00	80.00	41.75	44.00	50.30	193.00	482.54
20	530.00	389.00	1250.06	885.60	678.97	60.25	124.28	39.70	45.00	47.30	176.48	473.00
21	462.54	1690.27	999.23	778.81	569.46	58.00	97.24	38.50	53.00	43.30	173.42	439.92
22	420.38	2190.04	901.20	685.15	592.80	58.00	81.48	37.50	57.50	43.00	153.02	416.74
23	395.77	1059.65	849.93	635.30	725.11	55.00	91.53	39.30	59.75	53.30	315.73	395.88
24	2269.64	840.04	2480.42	593.10	592.86	51.00	99.52	38.30	56.00	50.30	514.75	342.32
25	4209.92	779.21	3110.09	587.23	472.59	48.00	87.21	37.50	55.00	64.25	389.71	321.93
26	1420.14	712.09	2919.71	954.14	458.00	51.00	72.74	40.00	55.00	75.51	422.23	309.30
27	1109.76	684.58	2279.93	2339.68	551.54	56.25	66.50	39.00	53.00	84.00	399.00	319.13
28	1179.61	620.12	1699.66	1429.78	483.06	48.26	65.24	35.75	48.00	134.47	306.57	308.66
29	1139.65	0.00	1269.87	1010.39	414.83	46.80	57.00	32.50	47.53	311.19	255.24	297.76
30	800.04	0.00	1049.59	835.71	392.42	83.49	59.50	29.75	48.00	497.50	239.87	283.22
31	730.82	0.00	922.94	0.00	447.58	0.00	52.50	28.75	0.00	397.04	0.00	264.44
MIN	219.98	370.00	370.38	587.23	392.42	46.80	52.50	28.75	25.00	42.25	94.99	207.93
MAX	4209.92	2190.04	4759.56	2339.68	1560.16	378.06	124.28	74.14	101.02	497.50	514.75	1929.85
MEAN	686.58	696.53	1282.33	1331.46	834.10	109.52	83.98	46.92	54.48	91.59	194.98	636.47
TOTAL	21283.93	19502.79	39752.3[illegible]	39943.76	25857.07	3285.46	2603.23	1454.48	1634.50	2839.22	5849.29	19730.62
S DEV	799.17	394.86	968.51	393.93	324.83	77.23	16.09	11.19	18.91	106.11	199.73	476.84

FIGURE III-15. Simulated Natural Flow 1953: Neversink River at Oakland Valley

CDM/ WATER RESOURCES ENGINEERS
SPRINGFIELD, VIRGINIA
NODE 2130

* * * * P H A S E 2 * * * *
* DELAWARE RIVER *

NATURAL FLOW SIMULATION
OCTOBER 6,1979
DELAWARE RIVER AT MONTAGUE 01438500

AVERAGE DAILY DISCHARGE SIMULATED FOR 1953 (CFS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	4830.77	10487.76	8524.41	14703.17	15366.05	5772.34	3655.31	1017.41	1314.32	1212.95	3959.71	4435.29
2	4439.94	10710.65	7254.45	13692.52	21392.96	4944.08	3154.75	702.89	1414.39	779.71	3005.19	4015.34
3	4500.46	9582.68	7400.96	13304.71	19822.07	4227.70	2752.45	625.19	1463.94	592.31	2602.16	3695.66
4	4288.75	9003.00	8792.26	11103.96	17512.64	3771.18	1796.62	562.69	1414.70	526.51	2219.92	3488.16
5	4121.90	8155.92	13298.22	9581.99	15686.73	3999.01	1273.15	732.61	1295.08	501.30	1954.36	3425.66
6	4120.55	7100.37	10929.65	9582.44	19496.91	3950.49	1250.98	979.15	749.32	1406.94	2249.59	3572.14
7	3678.56	8561.41	8766.45	13434.43	16915.05	4162.91	1461.11	673.35	942.39	1518.28	2828.33	17708.39
8	3460.19	12899.35	7133.89	24006.43	15897.74	4781.65	1583.38	518.54	1920.39	1324.46	1842.59	27704.46
9	3679.27	11512.46	6744.37	19234.51	15806.78	4504.97	1515.02	506.54	3373.32	1281.57	1697.65	19081.97
10	3637.21	9406.15	6591.41	16099.72	13706.67	3791.20	1453.15	676.19	2372.90	1359.59	2739.79	15640.00
11	4882.42	8154.61	6334.07	16699.30	12394.61	3090.76	1261.46	818.75	1468.90	1324.50	2646.77	19583.38
12	6439.93	8060.13	5909.53	13709.47	10803.15	2880.77	1160.96	717.24	1113.66	858.11	2499.16	13999.29
13	6250.58	7341.18	6678.01	14094.21	10003.65	2895.93	1139.10	1357.58	1195.65	1151.51	2739.82	12997.88
14	5332.94	6891.01	7934.81	16795.74	10000.30	3022.04	1813.09	949.67	1465.94	1280.17	2671.41	13338.77
15	4991.32	6589.83	8988.63	14513.11	9785.25	3224.65	1795.19	1275.06	1850.94	1148.47	2393.13	17319.00
16	4996.29	7395.78	22535.97	12999.32	9371.24	3223.99	1491.46	993.25	1626.24	867.55	2303.08	15351.76
17	5192.82	7952.94	22577.23	14099.95	9339.46	2822.40	1874.41	1485.70	1286.58	815.80	3216.02	12073.16
18	7334.02	6774.13	16504.96	12304.45	12378.03	2661.29	1819.49	1303.71	1092.36	692.72	2890.63	3940.91
19	10692.07	6278.84	14864.51	12093.16	11937.08	2491.04	1295.76	957.00	938.79	603.75	2692.93	3337.94
20	11208.43	5967.22	16595.87	12301.80	9963.80	2372.18	1156.68	588.53	831.90	532.87	2478.72	7176.44
21	9821.26	11108.34	13718.35	11903.70	8723.09	1810.88	1969.96	591.53	817.95	943.02	2476.25	7200.60
22	9181.98	29920.59	11206.38	11104.35	8001.76	1770.58	1972.75	550.25	1289.12	814.98	2259.17	7312.75
23	8342.22	20345.36	10703.66	10003.69	7457.72	2327.64	1968.75	516.41	974.56	768.90	2857.56	7244.00
24	15095.67	15008.51	13065.01	9213.79	7853.14	2240.21	1593.19	509.19	754.67	611.77	6534.29	5338.87
25	58275.42	13002.61	27792.94	8511.03	6771.55	2160.58	1138.65	964.44	713.59	567.56	7439.84	5132.39
26	38372.43	11703.69	28069.58	8478.97	6759.59	2219.72	937.95	911.33	715.16	578.19	6832.86	4569.74
27	22629.71	10800.46	30612.63	23647.54	6827.17	2409.34	867.04	832.93	765.10	752.48	7375.73	4757.33
28	18204.42	10002.58	26529.87	23341.16	6192.47	1370.95	1213.82	1119.21	611.42	1321.78	6052.52	4729.79
29	17206.24	0.00	21315.02	17515.83	5721.43	1640.95	1111.17	1108.08	757.04	2102.95	5224.27	5031.05
30	13708.56	0.00	17509.09	14506.58	5088.54	2551.53	1219.97	511.79	710.94	3924.72	4740.18	4544.93
31	11202.96	0.00	15804.42	0.00	5014.68	0.00	1317.81	509.71	0.00	4370.96	0.00	4252.04
MIN	3460.19	5967.22	5908.50	8478.97	5014.69	1370.95	867.04	506.64	611.42	501.30	1679.65	3425.66
MAX	58275.42	29920.59	30612.63	24006.43	21392.96	5772.34	3655.31	1495.70	3373.32	4370.96	7438.84	27704.46
MEAN	10645.81	10379.17	13898.28	13986.13	11348.33	3100.00	1614.02	815.05	1226.07	1172.80	3448.45	7421.44
TOTAL	330020.00	290616.64	430846.63	419580.79	351798.22	92999.96	50034.75	25266.60	36782.08	36356.70	103453.61	292064.56
S DEV	11297.62	4829.17	7292.93	3928.28	4589.57	1059.49	611.93	262.71	558.59	852.40	1702.19	5039.92

FIGURE III-16. Simulated Natural Flow 1953: Delaware River at Montague

AD-A110 112 CAMP DRESSLER AND MCKEE INC ANNANDALE VA F/G 13/2

DAILY FLOW MODEL OF THE DELAWARE RIVER BASIN. MAIN REPORT.(U)

SEP 81 DACW61-78-C-0127

UNCLASSIFIED DAEN/NAP-51850/DFM01-81/09 NL

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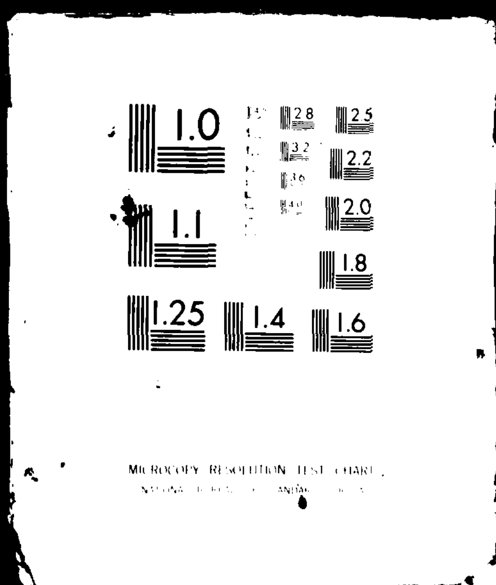


COMP WATER RESOURCES ENGINEERS • • • • P H A S E ? • • • • NATURAL FLOW SIMULATION
SPRINGFIELD, VIRGINIA • DELAWARE RIVER • OCTOBER 6,1979
NODE 2310 • • • DELAWARE RIVER AT TRENTON 2146331;

----------AVERAGE DAILY DISCHARGE SIMULATED FOR 1953 (CFS)----------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	10921.17	22207.77	17702.48	25807.32	24310.51	13127.92	4171.13	2390.15	1926.36	1916.97	7313.77	7197.92
2	10330.30	20498.16	15803.95	24203.76	26575.27	12799.09	5173.45	3398.45	1715.23	1934.71	6734.74	7485.85
3	10220.18	19500.52	13904.91	22997.67	30683.74	11502.82	5852.62	2898.59	1864.35	1972.98	5635.41	5962.44
4	10901.44	18005.91	20001.76	21799.55	27903.90	10004.10	5175.64	2672.16	2335.15	2083.14	4755.25	5451.96
5	10000.78	16404.45	24488.03	19594.34	25515.10	9192.31	4407.09	2471.16	2515.48	1852.94	4239.65	5582.71
6	9259.88	15904.38	24386.66	17503.69	24991.81	8720.18	3876.40	2343.50	3035.54	1773.39	3819.18	5805.63
7	8871.89	19802.99	20996.33	23298.55	27524.06	8509.58	3453.87	2325.33	4155.33	1793.99	3713.42	21501.96
8	8559.82	18993.24	17913.25	37770.02	26003.46	9567.58	3452.40	2477.29	4957.70	2370.44	4079.43	42456.16
9	12599.03	21491.04	15707.32	39571.20	23295.55	9676.18	3583.52	2505.97	3717.79	2673.42	4490.27	37303.95
10	17397.99	19703.98	14305.12	34913.08	24303.20	9352.51	3493.99	3102.21	3975.08	2421.77	3983.95	33439.26
11	17796.18	17008.73	13902.38	31116.10	21806.65	8214.36	3337.73	3340.72	4425.39	2367.45	3848.53	32102.26
12	16495.31	15405.73	13102.36	28602.13	19807.18	7142.84	3222.04	2975.99	3493.59	2409.27	4337.64	23698.26
13	15597.66	15303.17	17899.95	27603.19	17325.31	6351.00	3017.52	2611.19	2959.61	2219.78	4606.27	25841.39
14	14691.33	14400.07	17196.09	31001.38	17801.87	7519.55	2951.24	2490.21	2773.12	2042.70	4568.94	31874.86
15	13201.61	14600.42	18495.41	33397.41	17999.83	6954.84	2869.39	2560.72	2757.45	2091.84	4720.11	33002.93
16	12602.36	17999.03	28086.81	29133.24	17237.43	6867.37	3303.17	2493.40	2980.66	2251.22	4573.98	32090.36
17	127[illegible].84	16498.05	38570.78	24834.62	16998.76	5772.80	3303.28	2680.62	3326.89	2278.74	4532.67	27121.78
18	14194.18	16000.67	35104.09	27300.52	18709.66	6234.47	3039.45	2691.73	3098.44	2108.46	4888.22	21400.72
19	19391.40	14303.91	29730.98	27701.59	21407.06	5713.39	3233.24	2651.24	2632.42	1997.35	5314.11	17135.93
20	21393.48	13102.76	28893.14	26599.76	19602.81	5421.69	3258.15	2701.84	2491.43	1938.27	4955.15	13375.84
21	21499.67	14594.54	28083.74	24809.11	17206.26	5080.87	3565.82	2401.46	2374.97	1838.51	4712.62	13640.51
22	20853.54	29061.31	24603.86	23202.87	15403.74	5151.47	3409.25	2162.38	2231.73	1757.33	4486.76	12925.75
23	19162.11	42567.79	21211.84	21304.93	20391.34	5300.23	4541.74	1934.37	2111.07	1956.33	4943.96	13317.73
24	28293.17	31521.99	21494.24	19605.23	20100.74	4491.15	6881.96	1929.37	2244.22	1996.30	7445.42	12799.23
25	65332.13	25626.59	32783.77	18194.99	16509.49	4490.33	5471.16	1931.58	2196.06	1976.90	9330.26	11700.13
26	83050.50	22808.87	45275.37	17602.47	14701.52	4379.88	4104.96	1911.25	2025.31	1937.39	12383.36	11027.31
27	54330.04	20802.60	48083.36	23889.58	15299.83	4231.25	3397.30	1830.71	1927.90	1958.47	11387.94	9309.49
28	38543.31	19002.11	46695.74	35970.39	14197.22	4569.94	3172.43	2080.60	1910.07	2000.23	10959.57	8929.74
29	34019.57	0.00	40617.35	32994.79	12598.98	4690.62	3048.14	1990.93	1914.55	2755.56	9823.42	8765.76
30	30108.64	0.00	33421.03	27321.73	11809.45	4949.52	3093.42	2029.62	1897.61	7367.57	8625.14	7079.01
31	25109.43	0.00	28213.79	0.00	12492.99	0.00	3021.92	2197.23	0.00	7758.37	0.00	8599.48
MIN	8559.82	13102.76	13102.36	17503.69	11809.45	4949.52	2869.39	1811.25	1715.23	1757.33	3713.42	5451.96
MAX	83050.50	42567.79	48083.36	39571.20	30683.74	13127.92	6881.96	3340.72	4957.70	7758.37	12383.36	42456.16
MEAN	22159.67	19557.89	25693.41	26623.22	20055.24	7224.98	3799.55	2459.33	2725.38	2422.45	5972.50	18173.75
TOTAL	686949.86	547620.79	796495.79	798696.62	621743.37	216749.37	117785.39	76239.38	81752.29	75095.90	179175.14	563396.39
S DEV	16973.22	6232.81	10045.58	5752.36	5005.26	2535.25	956.23	409.52	839.06	1373.37	2458.51	11984.42

FIGURE III-17. Simulated Natural Flow 1953: Delaware River at Trenton

13. Neversink River at Oakland Valley, N.Y.,
14. Delaware River at Montague, N.J.,
15. Delaware River below Tocks Island Damsite, PA.,
16. Delaware River at Belvidere, N.Y.,
17. F.E. Walter Reservoir near White Haven, PA.,
18. Pohopoco Creek below Beltzville Dam, PA.,
19. Aquashicola Creek at Aquashicola Damsite, PA.,
20. Aquashicola Creek at Palmerton, PA.,
21. Lehigh River at Walnutport, PA.,
22. Jordan Creek near Schnecksville, PA.,
23. Jordan Creek at Allentown, PA.,
24. Lehigh River at Bethlehem, PA.,
25. Lehigh River at Glendon, PA.,
26. Musconetcong River near Hackettstown, N.J.,
27. Delaware River at Riegelsville, N.J.,
28. Tohickon Creek near Pipersville, PA.,
29. Delaware River at Trenton, N.J.,
31. Schuylkill River at Cressona, PA.,
32. Schuylkill River at Landingville, PA.,
33. Little Schuylkill River at Tamaqua, PA.,
34. Little Schuylkill River at Diehersville, PA.,
35. Schuylkill River at Berne, PA.,
36. Maiden Creek at Virginville, PA.,
37. Tulpehocken Creek at Blue Marsh Damsite, PA.,
38. Tulpehocken Creek near Reading, PA.,
39. Schuylkill River near Reading, PA.,
40. Schuylkill River at Pottstown, PA.,
41. Perkiomen Creek at Graterford, PA.,
42. Schuylkill River at Philadelphia, PA.,
43. Delaware River below Schuylkill Confluence, and
44. Delaware River at Delaware Memorial Bridge.

The duration and low flow frequency tables and plots from the natural flow model are presented in Appendix A.

The flow duration analysis consists of the development of a cumulative frequency distribution which shows the percentage of time the indicated flows have been equaled or exceeded. The distribution does not take into account the chronological sequence of flows and therefore does not indicate whether varying periods of low flow, for example, occurred during one dry weather period or were distributed over several years.

The low flow frequency analysis shows the relationship between the magnitude and frequency of the annual lowest mean flow for a given number of consecutive days. For each n-consecutive days analyzed, the log-Pearson Type III method is used to produce theoretical values which correspond to non-exceedance probabilities or recurrence intervals in years.

The duration and frequency results presented in Appendix A are for 50 years of naturalized flows at the 44 key locations throughout the Delaware River Basin. These characteristics are the basis for comparison to the regulated flow characteristics of the basin with the operation of the three New York City reservoirs during the 50-year base period.

The U.S. Geological Survey's Daily Values Statistics Program (A969) is used to develop the duration and flow frequency tables. The Philadelphia Corps of Engineers executed the program on the Boeing computer system in Vienna, Virginia from the input data supplied by WRE to them on magnetic tape and cards.

The A969 program is used to compute the number of times flow at a node equaled or exceeded a certain magnitude. The program tabulated the number of daily values in each of 35 magnitude classes for each year for each key location. The class limits are computed from a relationship between the lowest positive non-zero and the record highest daily value of the period being processed. A duration table is produced as output. A summary is produced with the duration table which gives the value of each class limit, the number of days in the period in each

class, the total number of days having a value greater than or equal to each class limit, and the percent of all days in which a class limit is equaled or exceeded. An example of the duration table and summary is shown in Figure III-18.

The flow duration analysis results for each of the 44 key locations are given in Table A-1 of Appendix A. Nine percentages are chosen for display in this table. The flows for each of these percentages are interpolated from the actual class limit values and the corresponding percentages given in the duration tables developed by the A969 program. Flow duration curves for the naturalized daily flows at the 44 key locations are shown on Figures A-1 to A-44 in Appendix A. These figures also show the duration curves for the regulated flows which are discussed in Chapter IV.

The low flow frequency analysis is conducted using the Log-Pearson Type III distribution and is based on the flow values of the low flow frequency table. The low flow table contains the lowest "n"-day mean value for each period of consecutive days in each water year begins October first. The table also includes a ranking of the flows according to magnitude in the period of years analyzed. An example of a low flow table produced by the A969 program is shown in Figure III-19.

The Log-Pearson low flow frequency tables from the A969 program contain a tabulation of the input data from the low flow table, the computed statistics of flow values and of logarithms, and a list of eleven non-exceedence probabilities with corresponding recurrence intervals and the theoretical flow values. An example of the Log-Pearson low flow frequency table for the one-day low value is shown in Figure III-20.

For each of the 44 key locations low flow frequency tables are produced for periods of 1, 3, 7, 14, 30, 60, 90, 120, 183 and 365 consecutive days. The naturalized low flow frequency results are given in Table A-2.1 to A-2.44 of Appendix A for the 44 locations. In each table the low flows for each of the ten consecutive day periods are given for eleven recurrence intervals and the corresponding probabilities.

STATION NUMBER 01438500

DURATION TABLE OF DAILY DISCHARGE FOR YEAR ENDING SEPTEMBER 30

DELAWARE RIVER AT MONTAGUE, N.J.

NUMBER OF DAYS IN CLASS

CLASS / YEAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	CFS_DAY
1928			2	1			1	10	13	22	19	26	24	22	28	20	27	29	22	23	12	16	11	13	6	8	2	2	5		2					4264269.
1929	18	16	24	26	38	24	36	27	15	13	12	7	5	11	6	11	11	9	12	11	7	3	7	2	4	2	2		2	1	1					2189539.
1930	8	13	19	10	21	15	14	32	32	39	17	15	24	16	16	15	11	13	9	9	7	2	3	3	2											1971007.
1931	41	33	47	19	28	15	9	13	17	17	10	10	12	8	12	10	10	15	7	4	9	5	5	6	1	1	1									1830121.
1932	31	24	18	19	23	18	10	16	15	25	24	26	17	16	12	11	8	15	10	4	5	6	5	4		2	2									1981814.
1933	20	5	13	13	12	9	12	12	16	23	26	35	27	23	17	15	7	21	13	9	4	7	9	4	6	2	2		1	1			1			2726167.
1934	3	10	16	12	23	14	10	21	28	30	34	34	24	27	17	7	10	11	9	6	8	5	3	2				1								2012347.
1935	2	4	6	9	10	12	18	32	27	25	39	26	11	15	26	15	22	28	7	5	8	5	3	4	2	1	1	1	1							2437096.
1936	22	17	15	4	39	25	12	28	21	14	15	16	26	23	13	10	5	9	7	5	5	6	6	5	7		2	1	2	1	1	1		1	2	2735576.
1937	1	2	7	6	7	11	16	20	20	31	31	27	26	27	26	20	15	17	13	12	5	8	5	5	3	2	2									2640636.
1938				1	3	8	9	19	23	36	35	41	20	28	27	26	16	22	20	10	2	4	5	1	2	2	1		2	1				1		2801376.
1939	21	14	14	22	24	11	8	23	23	20	22	24	20	19	10	11	7	7	8	19	9	3	14	3	5	1	1		2							2420483.
1940	4	3	11	23	45	35	29	32	22	14	16	17	12	15	14	13	12	16	4	2	2	2	5		2	5	5	2	1			1	1	1		2387604.
1941	34	5	10	19	32	20	17	16	17	33	31	28	17	20	22	12	8	8	7	3	4	4	2	1	2	2		1								1786849.
1942	36	9	14	10	11	26	38	24	32	24	22	20	11	8	13	11	12	14	8	5	4	2	3	3	1			1		2			1			1958657.
1943	28	8	11	12	16	6	10	3	5	3	16	31	19	30	23	22	22	25	17	12	11	6	9	6	6	4	1	1	1				1			3064391.
1944	66	12	21	17	29	22	21	22	16	13	19	22	8	11	8	9	7	14	7	7	3	3	2	3	2	2										1629983.
1945	3	4	14	13	9	4	5	25	26	24	23	17	15	27	22	24	15	27	15	14	10	5	3	6	4	4	2	3	1	1						2980223.
1946	5	2	3	7	25	9	14	9	24	25	38	25	23	20	24	25	11	22	21	8	5	6	3	5	1		3	2								2575021.
1947		2	1	5	19	32	31	30	32	22	25	10	11	15	9	19	19	24	13	13	9	4	6	7	2	3			1		1					2592999.
1948	17	1	11	17	26	24	23	24	23	20	27	19	18	14	18	11	15	14	11	6	5	5	5	1	2	1	2	3		1			2			2403085.
1949	57	17	16	14	33	9	11	5	9	13	20	18	18	23	23	25	10	14	11	6	2		3	2	2		1		2				1			2012419.
1950	12	7	7	8	15	15	14	26	22	21	20	25	26	26	34	20	16	18	6	7	3	3	3	2	3	1	1	1	2	1						2395442.
1951	6	11	9	11	23	25	12	26	20	24	24	17	12	9	16	13	16	33	15	10	7	2	6	6	3	2	2		1	1	2		1			2775660.
1952	8	5	3	10	14	14	18	23	10	10	21	17	21	11	21	21	26	35	16	14	13	4	12	6	3	5	3	1	1							3154567.
1953	65	19	22	16	18	6	5	5	6	8	11	14	6	19	17	17	17	24	19	13	11	6	7	5	4		2	1		1			1			2613327.
1954	92	9	10	3	9	15	14	20	17	7	15	19	15	18	23	15	12	11	12	10	6	4	4	2	2	1										1902904.
1955	35	11	6	14	19	11	19	16	12	21	23	20	19	15	17	19	22	18	21	7	6	4	4	3		1					1				1	2441329.
1956	42	7	8	7	8	12	5	15	16	19	20	17	22	24	25	16	15	14	15	13	8	7	4	9	6	3	3	3	1		1		1			3008731.
1957	70	11	10	12	14	14	22	21	22	16	22	22	17	21	12	12	7	12	9	10	1	2	1	2	2		1									1689917.
1958	55	23	20	13	13	12	7	20	21	24	11	18	16	11	13	10	8	18	10	6	7	2	2	8	7	5	1	1		2	1					2397279.
1959	62	14	17	16	15	15	9	11	17	21	19	14	19	20	18	19	12	12	13	9	3	4	1	2		1		2								1903696.
1960		3	2	3	3	14	9	22	27	23	23	36	29	34	24	18	16	24	13	8	5	6	2	6	3	3	2	2	1	3	1	1				3078268.
1961	9	12	22	23	33	30	19	17	31	23	20	13	10	18	11	11	6	14	12	8	3	1	7	3	4	1		1	2		1					2112899.
1962	136	13	9	11	11	17	14	18	18	17	9	15	10	9	6	8	6	5	13	7	3	2	1	2	1	1	1	1	1							1472445.
1963	44	13	13	10	12	24	21	34	26	33	42	23	16	14	6	6	6	6	1	3		1		4	2	1	1	1		1	1					1648460.
1964	107	21	7	10	11	8	9	19	10	24	23	15	8	12	12	13	16	12	9	5	3	2	1	2	2	1	1	2			1					1759155.
1965	153	23	16	9	7	9	12	19	11	20	19	13	8	7	11	4	6	8	7		1		2													1031980.

FIGURE III-18. Sample Duration Table From Program A969

STATION NUMBER 01438500

DURATION TABLE OF DAILY DISCHARGE FOR YEAR ENDING SEPTEMBER 30

DELAWARE RIVER AT MONTAGUE, N.J.

NUMBER OF DAYS IN CLASS

CLASS / YEAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1966	78	13	14	10	22	11	10	23	20	24	26	24	13	7	18	9	11	15
1967	8	12	11	8	15	24	19	33	33	36	29	22	13	19	12	17	10	16
1968	30	9	6	7	17	16	19	15	19	24	20	31	19	22	26	25	14	16
1969	32	3	13	13	16	25	21	20	12	12	26	28	23	17	13	20	19	17
1970	44	14	17	26	14	7	10	15	17	28	29	23	15	13	20	6	12	7
1971	27	10	10	12	16	15	13	20	12	39	31	17	14	6	21	24	15	19
1972	26	6	3	8	8	13	13	25	13	23	20	10	15	13	23	28	23	22
1973	14	8	8	9	9	12	11	10	14	12	13	23	13	29	25	26	18	25
1974	12	1	12	19	20	10	11	12	15	16	23	17	25	24	24	15	13	25
1975		1	1	6	13	12	15	29	13	13	21	28	27	39	22	23	17	27
1976			3	2	9	10	9	14	17	28	32	35	37	27	25	21	17	26
1977	32	14	14	26	26	23	8	23	18	15	17	7	12	12	7	10	12	23

CLASS / YEAR	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	CFS_DAYS
1966	7	4	2		4													1489103.0
1967	7	4	3	3	4	1	3	2	1									1977387.0
1968	6	3	3	6	1	5	4	2	1									2196889.0
1969	11	7	5	1	5	1	2	2		1								2096592.0
1970	8	5	9	7	10	4	2	1	1	1								2102146.0
1971	13	4	11	8	2	5	1											2189991.0
1972	8	14	13	4	8	7	12	5	2		1							3062479.0
1973	22	12	12	9	4	14	3	3	1	4		1				1		3337727.0
1974	20	14	8	6	12	3	2	1	2	1	1			1				2843996.0
1975	17	10	7	6	4	7	1	2	1		1	1	1					2870733.0
1976	19	9	7	4	1	4	3	4	1		1			1				2817572.0
1977	14	10	7	7	9	4	4	3	4	1	1	1					1	2663782.0

CLASS	CFS	TOTAL	ACCUM	PERCT	CLASS	CFS	TOTAL	ACCUM	PERCT	CLASS	CFS	TOTAL	ACCUM	PERCT	CLASS	CFS	TOTAL	ACCUM	PERCT
0	0.00	1616	18263	100.0	9	3400.00	1067	10652	58.3	18	12000.0	594	2406	13.2	27	41000	42	135	.7
1	1130.00	494	16647	91.2	10	3900.00	1130	9585	52.5	19	14000.0	419	1812	9.9	28	47000	35	93	.5
2	1300.00	586	16153	88.4	11	4500.00	1057	8455	46.3	20	16000.0	303	1393	7.6	29	54000	20	58	.3
3	1500.00	601	15567	85.2	12	5200.00	868	7398	40.5	21	18000.0	218	1090	6.0	30	62000	15	38	.2
4	1700.00	883	14966	81.9	13	5900.00	914	6530	35.8	22	20000.0	238	872	4.8	31	71000	5	23	.1
5	2000.00	768	14083	77.1	14	6800.00	878	5616	30.8	23	23000.0	203	634	3.5	32	81000	10	18	
6	2300.00	724	13315	72.9	15	7800.00	788	4738	25.9	24	27000.0	141	431	2.4	33	93000	4	8	
7	2600.00	994	12591	68.9	16	8900.00	668	3950	21.6	25	31000.0	93	290	1.6	34	110000	4	4	
8	3000.00	945	11597	63.5	17	10000.00	876	3282	18.0	26	36000.0	62	197	1.1					

FIGURE III-18. Sample Duration Table From Program A969
(CONTINUED)

STATION NUMBER 01438500

LOWEST MEAN DISCHARGE, IN CFS, AND RANKING, FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPTEMBER 30

DELAWARE RIVER AT MONTAGUE, N.J.

YEAR	1	3	7	14	30	60	90	120	183	ANNUAL
1928	1310.00 48	1440.00 47	2890.00 50	3120.00 50	4490.00 50	5710.00 50	6710.00 50	8160.00 50	10400.00 50	11700.00
1929	744.00 33	811.00 29	939.00 28	1070.00 28	1300.00 27	1360.00 17	1550.00 18	1920.00 17	5430.00 28	6000.00
1930	809.00 36	1030.00 38	1150.00 37	1190.00 32	1380.00 31	1590.00 27	1770.00 22	2530.00 23	3510.00 5	5400.00
1931	717.00 31	861.00 34	887.00 26	934.00 23	1010.00 19	1180.00 12	1430.00 13	1420.00 6	2930.00 2	5010.00
1932	657.00 26	796.00 27	871.00 25	911.00 21	1170.00 22	1430.00 21	1940.00 25	2780.00 28	5220.00 23	5410.00
1933	760.00 35	825.00 31	1070.00 34	1220.00 33	1330.00 28	1460.00 24	1950.00 26	2840.00 29	6410.00 40	7470.00
1934	937.00 40	1190.00 41	1340.00 41	1460.00 40	1540.00 36	1990.00 34	2420.00 31	2700.00 26	5080.00 19	5510.00
1935	1120.00 44	1390.00 46	1590.00 45	1670.00 44	1780.00 42	2100.00 37	3770.00 43	3600.00 35	5180.00 21	6680.00
1936	677.00 27	825.00 32	1070.00 35	1170.00 31	1380.00 32	1750.00 29	1750.00 21	2090.00 19	4520.00 16	7470.00
1937	1060.00 43	1320.00 44	1380.00 42	1460.00 41	2450.00 47	3280.00 46	3580.00 42	4360.00 45	7120.00 44	7230.00
1938	1630.00 50	1890.00 59	2210.00 49	2290.00 49	3550.00 49	4730.00 49	5010.00 49	6150.00 47	6780.00 42	7680.00
1939	527.00 19	694.00 22	991.00 29	1140.00 29	1260.00 26	1420.00 19	1450.00 14	1620.00 10	4540.00 17	6630.00
1940	825.00 37	1090.00 39	1460.00 43	1510.00 42	1720.00 41	1870.00 31	2550.00 34	2770.00 27	4070.00 12	6520.00
1941	499.00 15	541.00 10	596.00 8	705.00 8	893.00 12	1430.00 22	1560.00 19	1760.00 14	3840.00 9	4900.00
1942	581.00 21	630.00 17	658.00 11	729.00 9	799.00 9	1230.00 15	2150.00 29	2660.00 25	4490.00 15	5370.00
1943	436.00 8	593.00 14	713.00 17	856.00 17	987.00 17	1210.00 13	1480.00 15	2590.00 24	6280.00 38	8400.00
1944	503.00 17	601.00 15	681.00 12	746.00 11	796.00 8	968.00 7	1330.00 10	1640.00 12	4190.00 14	4450.00
1945	989.00 42	1210.00 42	1310.00 39	1400.00 38	1610.00 40	2040.00 36	3320.00 41	4030.00 40	7580.00 46	8160.00
1946	695.00 29	970.00 37	1330.00 40	1460.00 39	1560.00 39	2110.00 38	2470.00 33	3690.00 36	5220.00 24	7050.00
1947	1150.00 45	1290.00 43	1770.00 47	1930.00 46	2090.00 44	2300.00 41	2430.00 32	3400.00 34	5210.00 22	7100.00
1948	689.00 28	803.00 28	1220.00 38	1280.00 34	1400.00 33	1870.00 32	2320.00 30	3260.00 33	6210.00 36	6570.00
1949	477.00 10	552.00 11	790.00 21	894.00 19	1040.00 21	1090.00 10	1170.00 8	1490.00 8	3710.00 6	5510.00
1950	726.00 32	751.00 25	869.00 24	957.00 25	1190.00 24	2000.00 35	3260.00 39	3900.00 38	6530.00 41	6560.00
1951	982.00 41	1100.00 40	1140.00 36	1380.00 37	1540.00 37	2180.00 40	2690.00 35	2870.00 30	5080.00 20	7600.00
1952	844.00 38	950.00 36	1050.00 33	1530.00 43	2080.00 43	2580.00 42	3860.00 46	4170.00 43	7670.00 47	8620.00
1953	507.00 18	525.00 8	643.00 9	746.00 12	808.00 10	1020.00 9	1170.00 9	1620.00 11	5340.00 26	7160.00
1954	371.00 6	510.00 7	580.00 7	624.00 7	656.00 6	750.00 6	1010.00 6	1420.00 7	4170.00 13	5210.00
1955	497.00 14	624.00 16	805.00 22	857.00 18	912.00 13	1420.00 20	1920.00 23	3220.00 32	5630.00 32	6690.00
1956	420.00 7	422.00 5	472.00 5	557.00 6	674.00 7	1010.00 8	1340.00 11	2400.00 21	6990.00 43	8220.00
1957	444.00 9	472.00 6	493.00 6	524.00 5	568.00 5	743.00 5	869.00 5	1180.00 4	3760.00 7	4630.00
1958	492.00 12	555.00 12	702.00 16	801.00 14	999.00 18	1230.00 14	1540.00 17	2000.00 18	5690.00 33	6570.00
1959	494.00 13	540.00 9	695.00 15	856.00 15	1020.00 20	1110.00 11	1160.00 7	1260.00 5	3930.00 11	5220.00
1960	1230.00 46	1360.00 45	1470.00 44	1950.00 47	2680.00 48	3160.00 45	4270.00 48	4560.00 46	7270.00 45	8410.00
1961	644.00 24	780.00 26	1010.00 31	1350.00 36	1520.00 35	1850.00 30	1930.00 24	2520.00 22	5740.00 35	5790.00
1962	316.00 5	380.00 4	418.00 4	473.00 4	518.00 2	597.00 3	618.00 1	770.00 1	3840.00 10	4030.00
1963	592.00 22	712.00 24	863.00 23	902.00 20	973.00 16	1390.00 18	1530.00 16	1820.00 15	3780.00 8	4520.00
1964	198.00 1	273.00 1	411.00 2	447.00 2	551.00 4	590.00 2	717.00 2	983.00 2	3190.00 3	4810.00
1965	263.00 3	323.00 3	415.00 3	429.00 1	473.00 1	522.00 1	852.00 4	1010.00 3	2650.00 1	2830.00

FIGURE III-19. Sample Low Flow Table From Program A969

STATION NUMBER 01438500

LOWEST MEAN DISCHARGE, IN CFS, AND RANKING, FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPTEMBER 30

DELAWARE RIVER AT MONTAGUE, N.J.

YEAR	1		3		7		14		30		60		90		120		183		ANNUAL
1966	225.00	2	275.00	2	379.00	1	461.00	3	542.00	3	613.00	4	782.00	3	1570.00	9	3280.00	4	4080.00
1967	701.00	30	938.00	35	1030.00	32	1140.00	30	1350.00	30	2140.00	39	2810.00	36	3130.00	31	4910.00	18	5420.00
1968	535.00	20	655.00	20	779.00	20	993.00	26	1190.00	25	1470.00	25	1990.00	28	3810.00	37	5600.00	38	6000.00
1969	645.00	25	707.00	23	753.00	18	942.00	24	1340.00	29	3470.00	48	4110.00	47	4260.00	44	5510.00	29	5740.00
1970	622.00	23	639.00	19	681.00	13	784.00	13	925.00	14	1580.00	26	1600.00	20	1860.00	16	5700.00	34	5760.00
1971	487.00	11	634.00	18	692.00	14	737.00	10	892.00	11	1440.00	23	1950.00	27	2240.00	20	5310.00	25	6000.00
1972	502.00	16	664.00	21	761.00	19	856.00	16	949.00	15	1600.00	28	3180.00	38	6270.00	48	7780.00	48	8370.00
1973	758.00	34	814.00	30	938.00	27	1310.00	35	1480.00	34	2990.00	44	3780.00	44	6460.00	49	8770.00	49	9140.00
1974	844.00	39	861.00	33	1000.00	30	1040.00	27	1560.00	38	1990.00	33	3310.00	40	4070.00	41	6330.00	39	7790.00
1975	1280.00	47	1480.00	48	1820.00	48	2000.00	48	2310.00	46	2790.00	43	2920.00	37	4080.00	42	6220.00	37	7870.00
1976	1390.00	49	1540.00	49	1760.00	46	1850.00	45	2140.00	45	3460.00	47	3790.00	45	3960.00	39	5420.00	27	7700.00
1977	296.00	4	579.00	13	654.00	10	933.00	22	1180.00	23	1350.00	16	1410.00	12	1690.00	13	5620.00	31	7300.00

FIGURE III-19. Sample Low Flow Table From Program A969
(CONTINUED)

DELAWARE RIVER AT MONTAGUE, N.J. N = 50 STATION 01438500

1928-1977, 12 MON PERIOD ENDING SEPTEMBER 30

1 DAY LOW FLOW

INPUT DATA (ZERO VALUES OMITTED)

1310.000	744.000	809.000	717.000	657.000	760.000	937.000	1120.000	677.000	1060.000
1630.000	527.000	825.000	499.000	581.000	436.000	503.000	989.000	695.000	1150.000
689.000	477.000	726.000	982.000	844.000	507.000	371.000	497.000	420.000	444.000
492.000	494.000	1230.000	644.000	316.000	592.000	198.000	263.000	225.000	701.000
535.000	645.000	622.000	487.000	502.000	758.000	844.000	1280.000	1390.000	296.000

MEAN = 701.940

VARIANCE = 100271.625

STANDARD DEVIATION = 316.657

SKEWNESS = 0.893

STANDARD ERROR OF SKEWNESS = 0.337

SERIAL CORRELATION COEFFICIENT = 0.291

COEFFICIENT OF VARIATION = 0.451

MEAN LOGS = 2.803

VARIANCE LOGS = 0.040

STANDARD DEVIATION LOGS = 0.201

SKEWNESS LOGS = -0.311

STANDARD ERROR OF SKEWNESS LOGS = 0.337

SERIAL CORRELATION COEFFICIENT LOGS = 0.368

COEFFICIENT OF VARIATION LOGS = 0.072

NON EXCEED PROB	RECURRENCE INTERVAL	DISCHARGE
0.0100	100.00	194.648
0.0200	50.00	227.394
0.0500	20.00	285.071
0.1000	10.00	346.008
0.2000	5.00	433.617
0.5000	2.00	650.277
0.8000	1.25	942.631
0.9000	1.11	1129.607
0.9600	1.04	1356.833
0.9800	1.02	1519.454
0.9900	1.01	1676.544

FIGURE III-20. Sample Log-Pearson Low Flow Frequency Table Table From Program A969

Low flow frequency curves for the 7-day, and 120-day periods are given on Figures A-45 to A-62 in Appendix A for 18 key locations. These curves indicate for a given magnitude of flow the recurrence interval in years and the non-exceedence probability in percent for each of the two periods of n-consecutive days.

Duration and Frequency Comparison of Observed and Simulated Flows

Several key locations have been chosen to compare the duration and frequency curves of the 50 years of naturalized flows developed by the model and the observed flows from the unregulated period of record. These locations are at the following USGS gaging stations:

East Branch Delaware River at Fishs Eddy, N.Y.,
West Branch Delaware River at Hale Eddy, N.Y.,
Neversink River at Oakland Valley, N.Y.,
Delaware River at Montague, N.J., and
Delaware River at Trenton, N.J.

The first three stations are downstream from the three New York City reservoirs and the other two are on the mainstem of the Delaware.

Figure III-21 presents the duration curves for Fishs Eddy, Hale Eddy and Oakland Valley, and Figure III-22 presents the duration curves for Montague and Trenton. The solid lines represent the curves for the 50 years of naturalized flows and the dashed lines represent the curves for the unregulated period of record of observed flows. Figures III-23 through III-27 present for each of the five locations the 7-day, 90-day and 365-day low flow frequency curves. As with the duration curves the solid lines represent the naturalized flows for 50 years and the dashed lines represent the observed flows for the unregulated period of record.

The duration curves for all five stations show that for the lower flows the simulated values are less than the observed values. With a few exceptions the frequency plots also give the same results. In some instances the simulated flows are less than the observed flows for the entire range of return intervals.

These results reflect differences in the data base used to analyze the frequency and duration. The unregulated period of observed flows is less than 50 years for which naturalized flows have been developed. For Fishs Eddy the unregulated period of records is 26 years; for Hale Eddy, 35 years, for Oakland Valley, 24 years; for Montague, 13 years, and for Trenton, 25 years. One of the major factors in the difference is the fact that the observed flows do not include the drought of the 1960's. The naturalized flow model simulates the 50 years of flow based on the correlation and fill-in analysis described in Chapter II. The simulated flows include the drought of the 1960's and several years of low flow periods are input into the frequency and duration analysis. This produces curves which when compared to the observed curves have lower flows for the given return intervals on the frequency plots and lower flows for the percent the flow was equaled or exceeded on the duration plots.

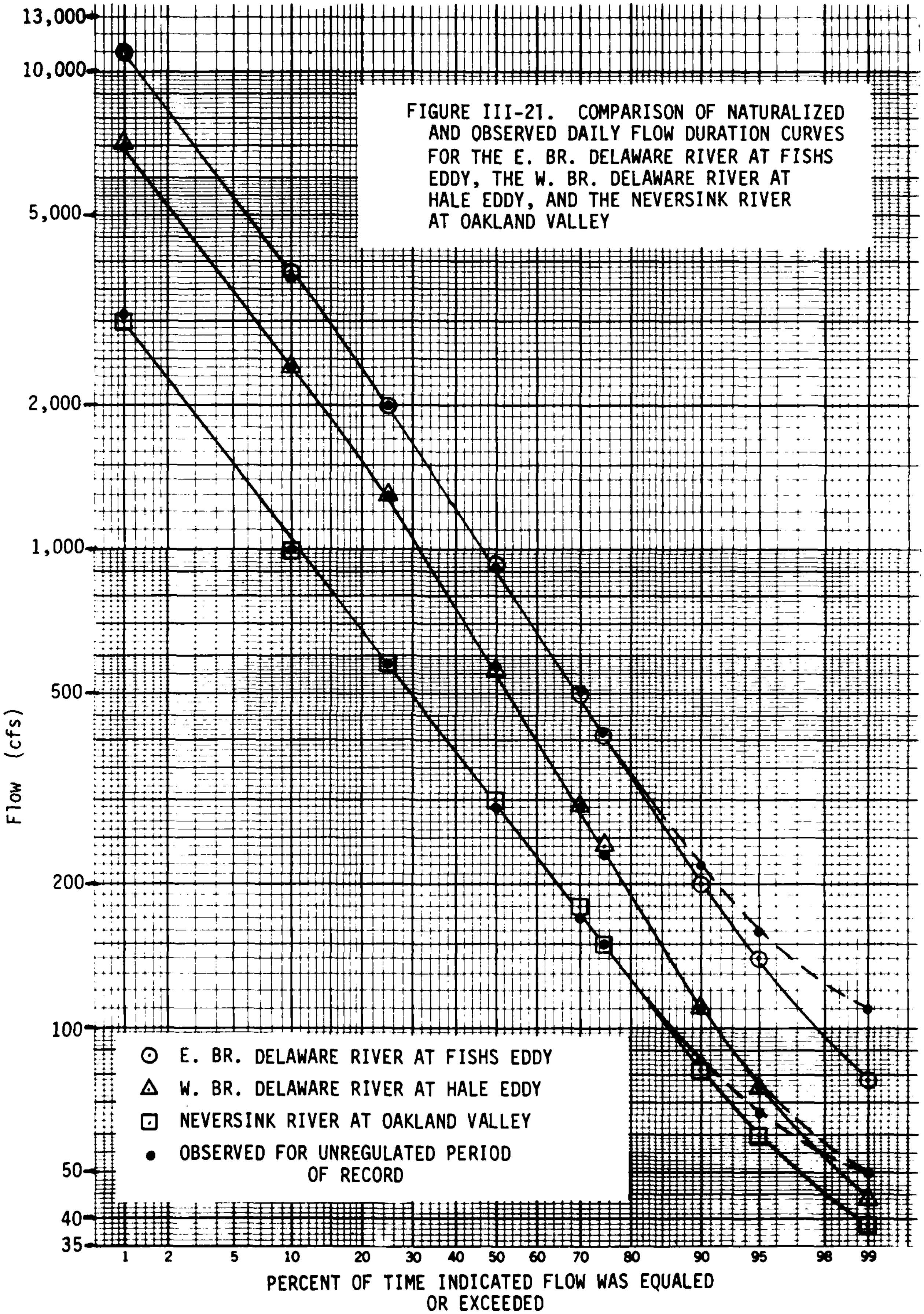


FIGURE III-21. COMPARISON OF NATURALIZED AND OBSERVED DAILY FLOW DURATION CURVES FOR THE E. BR. DELAWARE RIVER AT FISHS EDDY, THE W. BR. DELAWARE RIVER AT HALE EDDY, AND THE NEVERSINK RIVER AT OAKLAND VALLEY
13,000
10,000
5,000
2,000
1,000
500
200
100
50
40
35
Flow (cfs)
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
PERCENT OF TIME INDICATED FLOW WAS EQUALED OR EXCEEDED
E. BR. DELAWARE RIVER AT FISHS EDDY
W. BR. DELAWARE RIVER AT HALE EDDY
NEVERSINK RIVER AT OAKLAND VALLEY
OBSERVED FOR UNREGULATED PERIOD OF RECORD

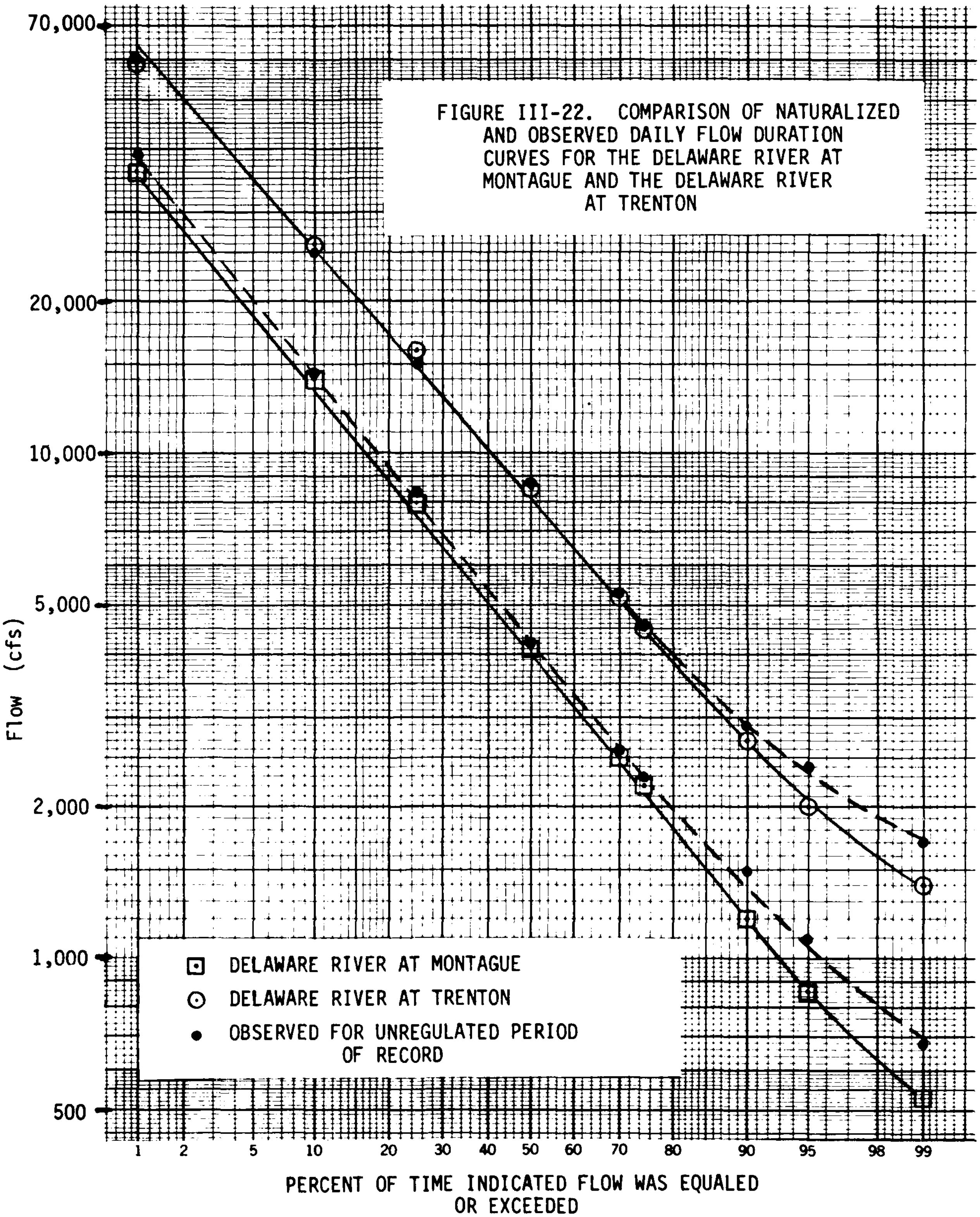
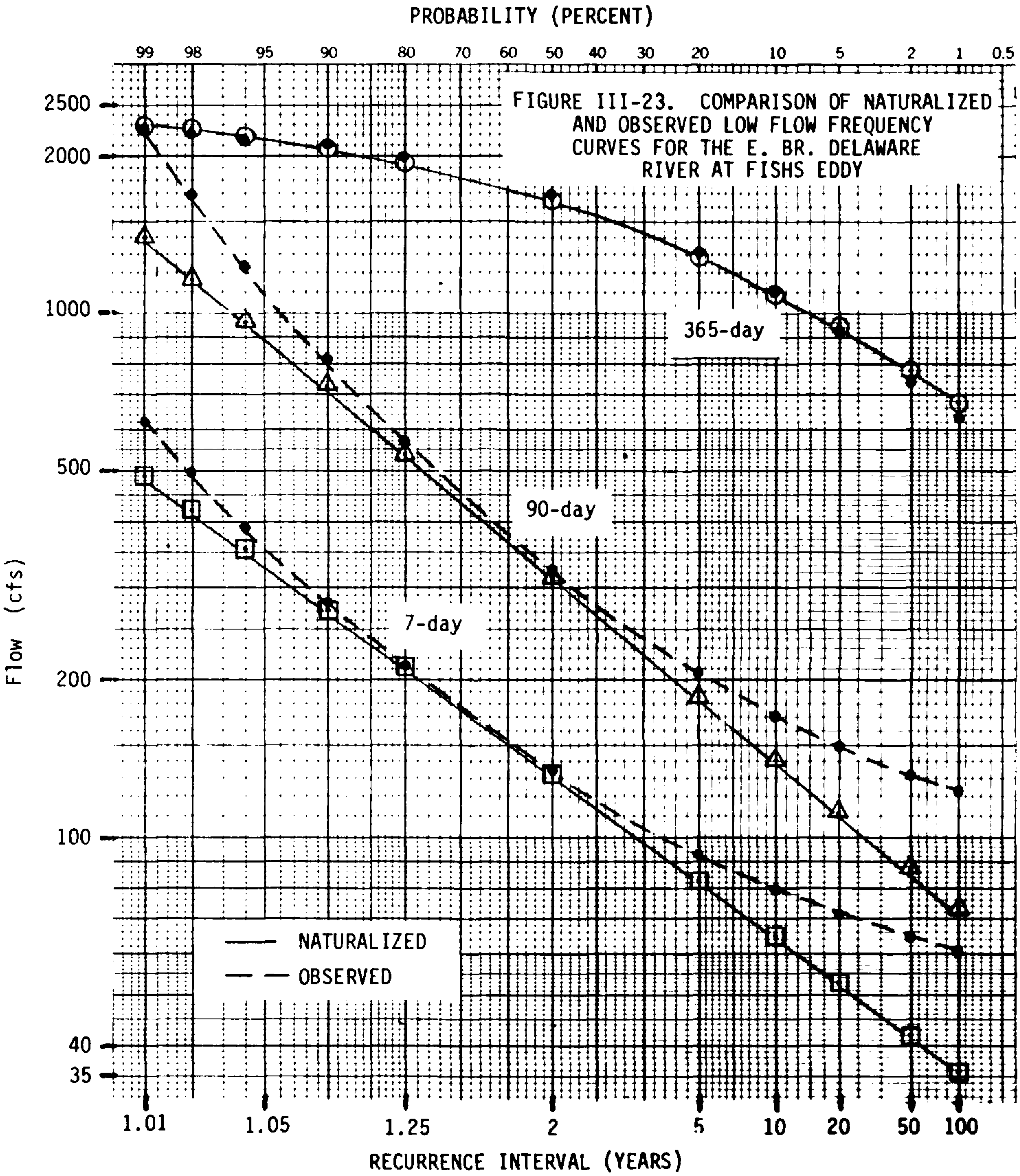
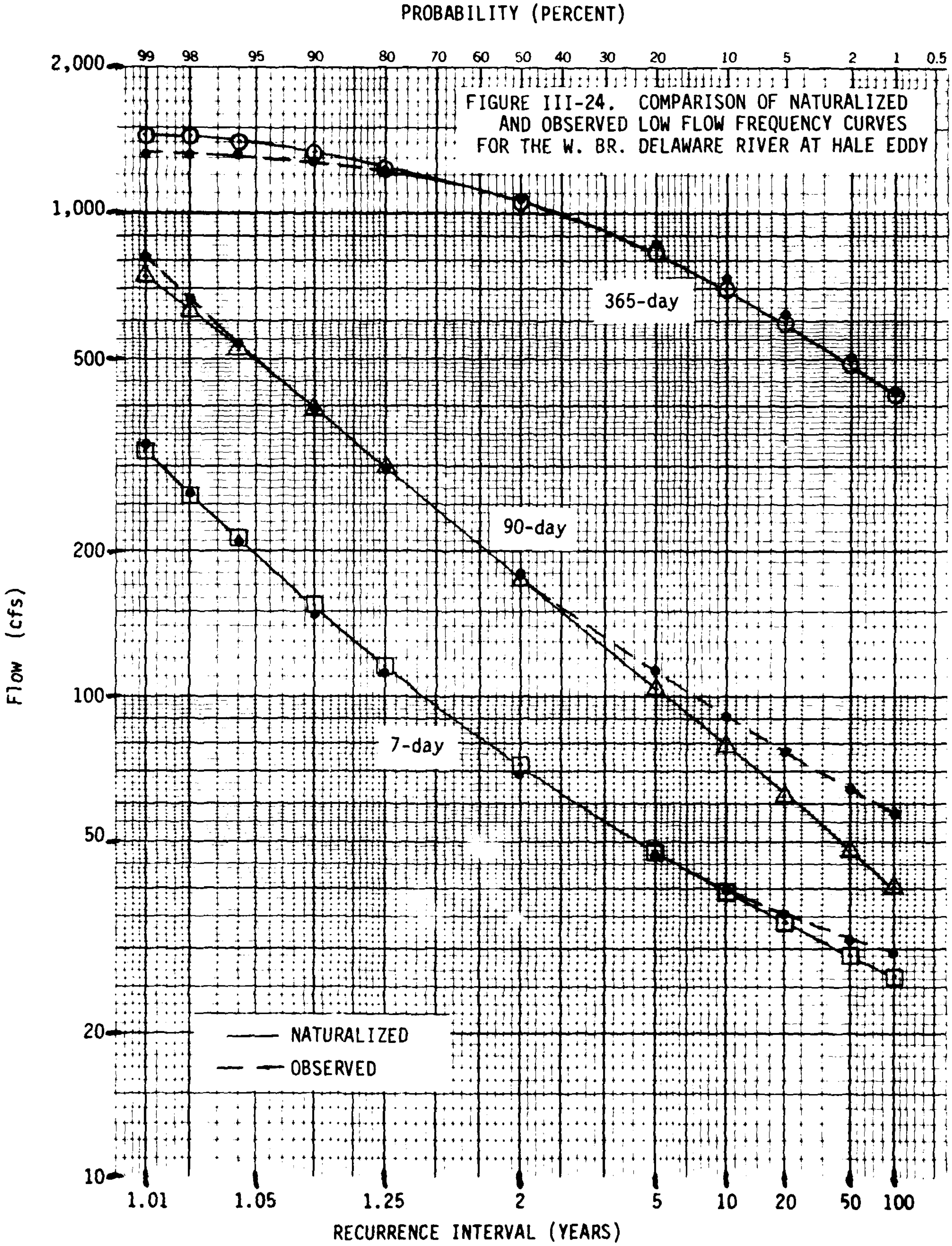


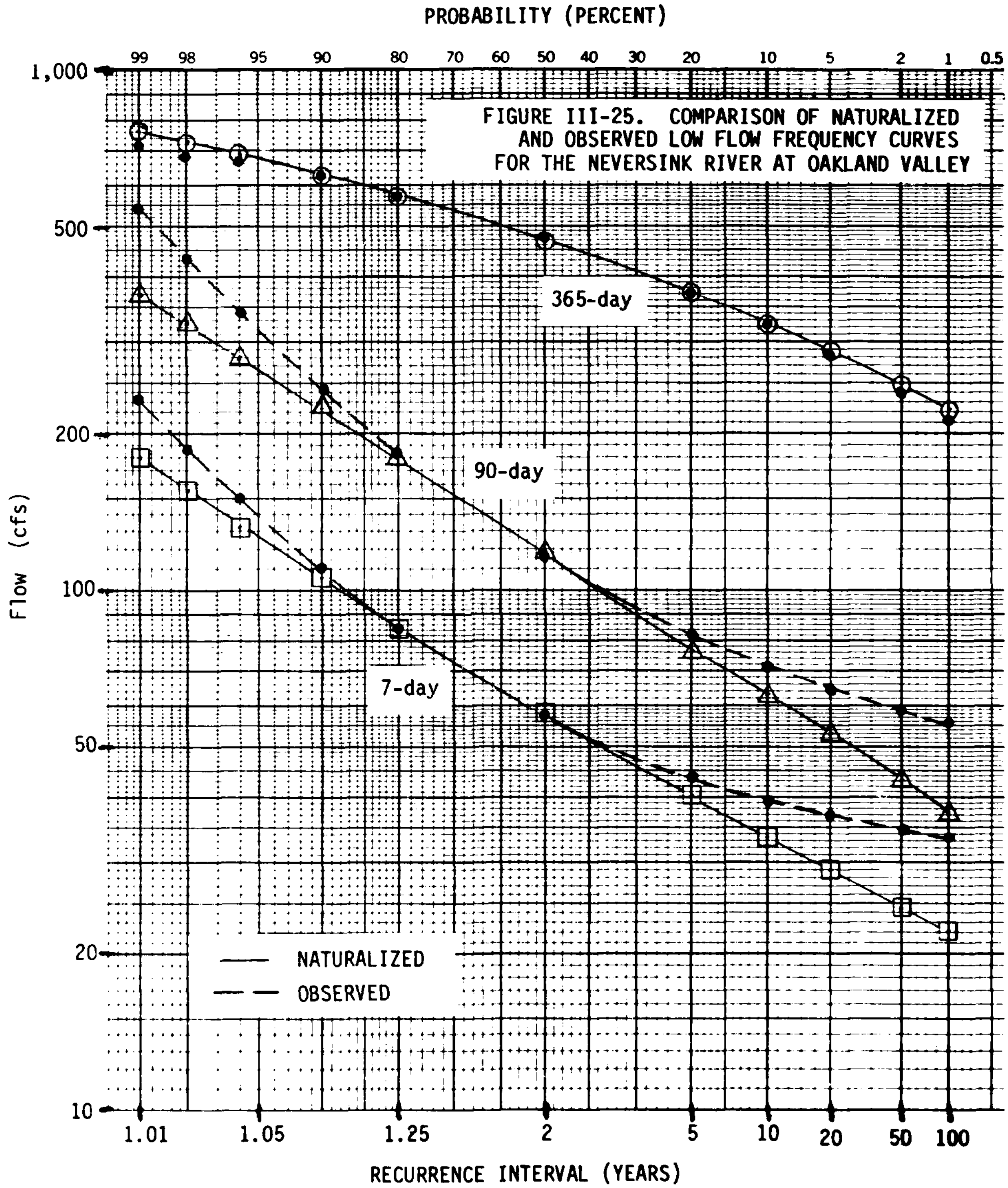
FIGURE III-22. COMPARISON OF NATURALIZED AND OBSERVED DAILY FLOW DURATION CURVES FOR THE DELAWARE RIVER AT MONTAGUE AND THE DELAWARE RIVER AT TRENTON
70,000
20,000
10,000
5,000
2,000
1,000
500
Flow (cfs)
DELAWARE RIVER AT MONTAGUE
DELAWARE RIVER AT TRENTON
OBSERVED FOR UNREGULATED PERIOD OF RECORD
1 2 5 10 20 30 40 50 60 70 80 90 95 98 99
PERCENT OF TIME INDICATED FLOW WAS EQUALED OR EXCEEDED



PROBABILITY (PERCENT)
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
FIGURE III-23. COMPARISON OF NATURALIZED AND OBSERVED LOW FLOW FREQUENCY CURVES FOR THE E. BR. DELAWARE RIVER AT FISHS EDDY
2500
2000
1000
500
200
100
40
35
Flow (cfs)
365-day
90-day
7-day
NATURALIZED
OBSERVED
1.01
1.05
1.25
2
5
10
20
50
100
RECURRENCE INTERVAL (YEARS)



PROBABILITY (PERCENT)
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
FIGURE III-24. COMPARISON OF NATURALIZED AND OBSERVED LOW FLOW FREQUENCY CURVES FOR THE W. BR. DELAWARE RIVER AT HALE EDDY
2,000
1,000
500
200
100
50
20
10
365-day
90-day
7-day
Flow (cfs)
NATURALIZED
OBSERVED
1.01
1.05
1.25
2
5
10
20
50
100
RECURRENCE INTERVAL (YEARS)


PROBABILITY (PERCENT)
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5
FIGURE III-25. COMPARISON OF NATURALIZED AND OBSERVED LOW FLOW FREQUENCY CURVES FOR THE NEVERSINK RIVER AT OAKLAND VALLEY
365-day
90-day
7-day
NATURALIZED
OBSERVED
Flow (cfs)
1,000
500
200
100
50
20
10
1.01 1.05 1.25 2 5 10 20 50 100
RECURRENCE INTERVAL (YEARS)

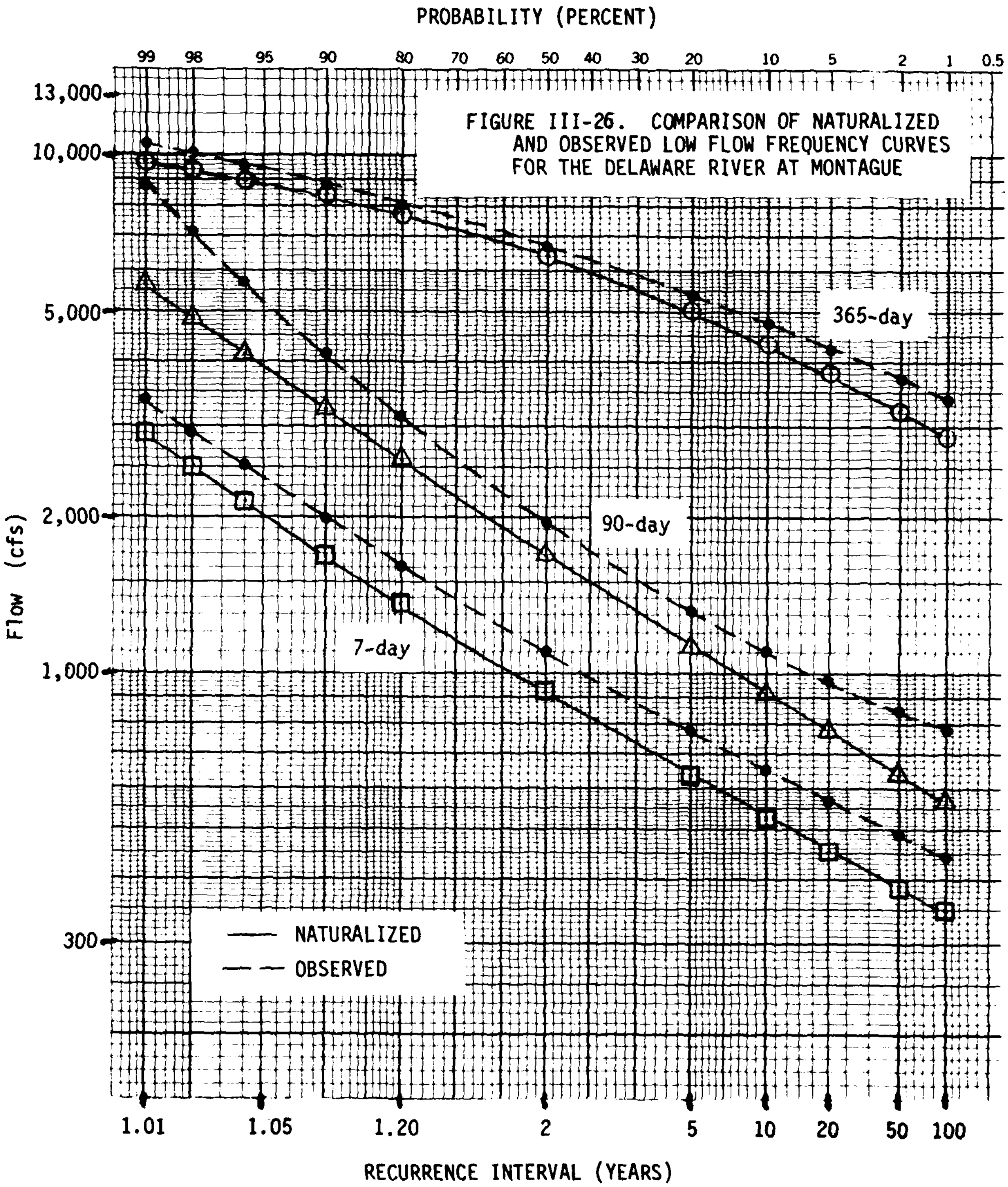
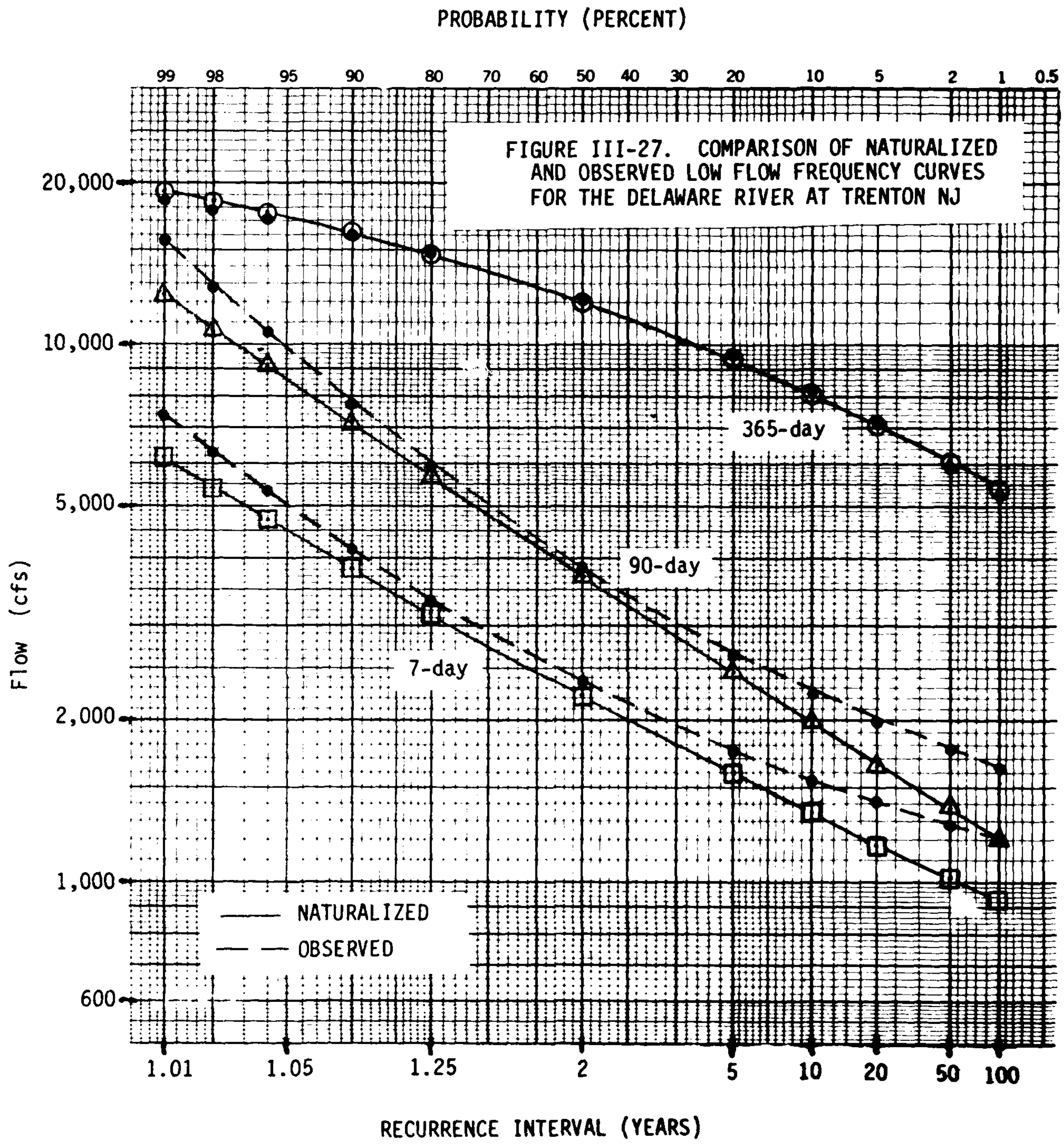


FIGURE III-26. COMPARISON OF NATURALIZED AND OBSERVED LOW FLOW FREQUENCY CURVES FOR THE DELAWARE RIVER AT MONTAGUE


PROBABILITY (PERCENT)
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5
FIGURE III-27. COMPARISON OF NATURALIZED AND OBSERVED LOW FLOW FREQUENCY CURVES FOR THE DELAWARE RIVER AT TRENTON NJ
20,000
10,000
5,000
2,000
1,000
600
Flow (cfs)
365-day
90-day
7-day
NATURALIZED
OBSERVED
1.01 1.05 1.25 2 5 10 20 50 100
RECURRENCE INTERVAL (YEARS)

IV. REGULATED FLOW MODEL

PURPOSE

The purpose of the regulated flow model is to determine the effect of New York City reservoir projects on the low flow frequency and flow duration analyses at key locations in the Delaware River Basin. Because this study is to analyze the low flow periods, sophisticated routing techniques are not required. The emphasis instead is on the ability of the model to match the desired flow condition within the constraints of the reservoir operating rules.

INCREMENTAL RUNOFF AND ROUTING PROCEDURES

The incremental inflow which is used in the natural flow model is also used in the regulated flow model with one major exception. The natural inflows, developed with the correlation and extension procedures, for the three New York City reservoirs, Pepacton, Cannonsville and Neversink, are replaced with daily net inflows to the reservoirs during the regulated period of record. The daily net inflows, obtained from the New York City Bureau of Water Supply files of Daily Yields in the Delaware Watershed, take into consideration the precipitation and evaporation over the reservoir surface. The periods for which the reservoir inflow data are available are given in Table IV-1.

The net evaporation for the New York City reservoirs during the unregulated period of record is accounted for in the regulated flow model by subtracting the net evaporation from the reservoir storage. The net evaporation which is simulated in the daily model is based on monthly averages of evaporation and precipitation. Evaporation data are obtained

TABLE IV-1

PERIODS OF RECORDED NET INFLOW DATA
FOR THE NEW YORK CITY RESERVOIRS*

Reservoir	Period of Record
Pepacton	9/17/54-5/31/55 7/1/55-9/30/77
Cannonsville	10/1/63-9/30/77
Neversink	7/1/53-12/31/53 2/1/54-7/31/59 1/1/60-9/30/77

*Periods are those which were used in the regulated flow model.

from the Climatic Atlas of the United States[1]. The average annual lake evaporation for the Delaware River Basin in the region of the reservoirs is divided into two six-month periods with 75 percent of the average annual evaporation occurring in the months May through October. Average monthly precipitation data are obtained from the Report of the River Master of the Delaware River[2]. The monthly averages are for the Delaware River Basin above Montague, New Jersey for the period December 1940 to November 1975.

The flow correlation and extension procedures for the unregulated period of record account for the runoff over the area of the reservoir site. In order to avoid double accounting of that percentage of the precipitation which occurs as runoff, the net evaporation is calculated as the evaporation minus one-half the precipitation. This analysis assumes that the direct runoff is 50 percent of the precipitation. Table IV-2 gives the monthly average evaporation, one-half the precipitation and net evaporation which is used in the regulated flow model for the unregulated period of record. The simulation of the net evaporation is also used for the periods of missing daily net inflows to the reservoirs during the regulated period of record as shown in Table IV-1 for Pepacton and Neversink reservoirs.

Identical routing procedures are used in the regulated flow model as are used in the natural flow model.

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[1] Climatic Atlas of the United States, U.S. Department of Commerce, Environmental Science Services Administration, June 1968.

[2] Report of the River Master of the Delaware River, for the Period December 1, 1975 - November 30, 1976, United States Department of the Interior, Geological Survey National Center, Reston, Virginia, 1977.

TABLE IV-2

NET EVAPORATION FOR NEW YORK CITY RESERVOIRS
(INCHES/MONTH)

Month	Evaporation[1]	One-half Precipitation[2]	Net Evaporation
Jan	1.208	1.400	-0.192
Feb	1.208	1.375	-0.167
Mar	1.208	1.620	-0.412
Apr	1.208	1.800	-0.592
May	3.625	2.075	1.550
Jun	3.625	1.995	1.630
Jul	3.625	2.080	1.545
Aug	3.625	2.010	1.615
Sep	3.625	1.800	1.825
Oct	3.625	1.555	2.070
Nov	1.208	1.920	-0.712
Dec	1.208	1.795	-0.587
Totals	28.998	21.425	7.573

[1] Source: Climatic Atlas of the United States, U.S. Department of Commerce, Environmental Science Services Administration, June 1968 (75% of annual occurs in May through October).

[2] Source: Report of the River Master of the Delaware River, For the Period December 1, 1975 - November 30, 1976, United States Department of the Interior, Geological Survey National Center, Reston, Virginia, 1977.

NEW YORK CITY RESERVOIR OPERATING PROCEDURE

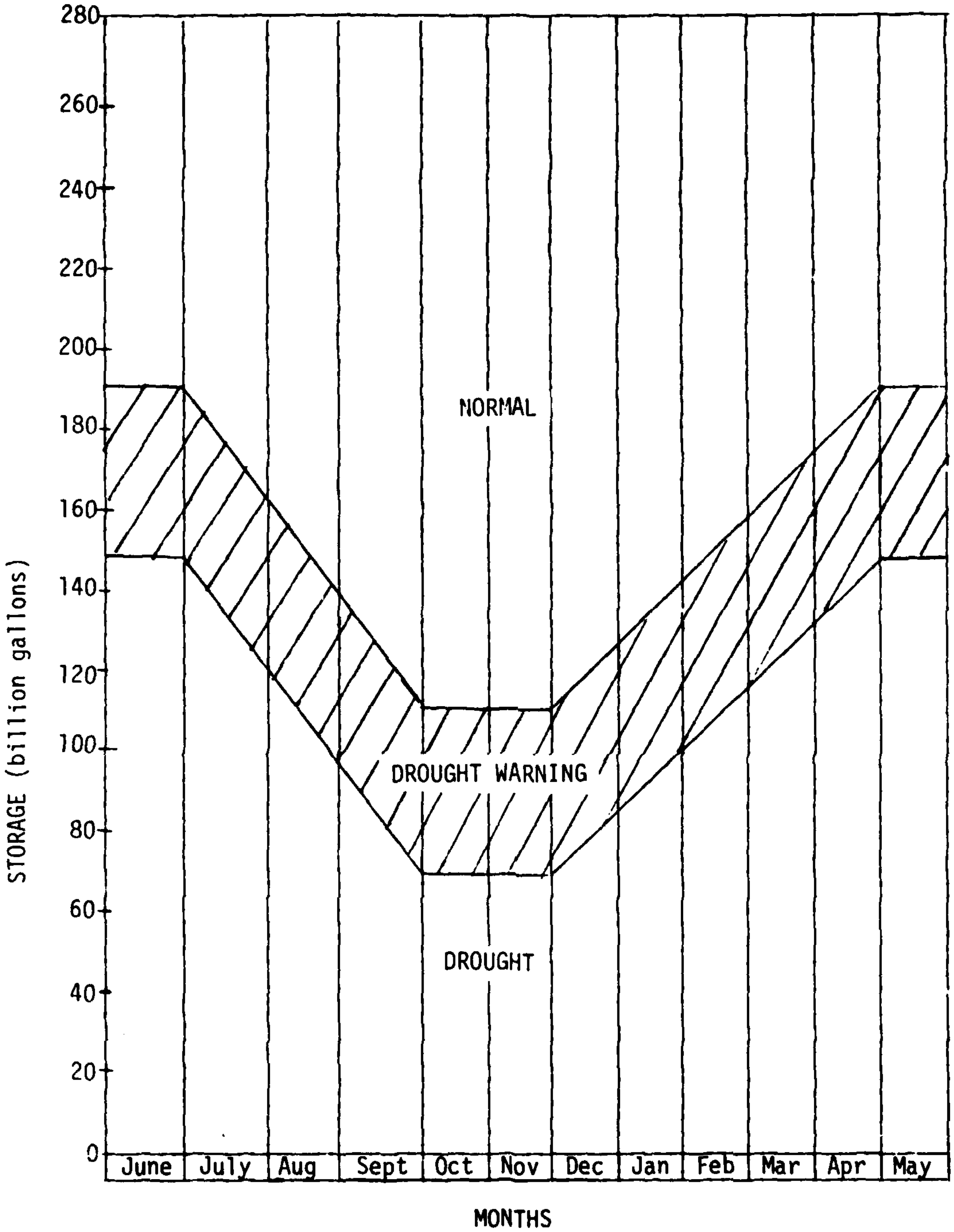
The operation rules for diversion and releases from Cannonsville, Pepacton and Neversink Reservoirs are as follows:

- The total daily New York City water supply diversion is withdrawn from only one of the three reservoirs each day. The criterion for selection is based on the reservoir which is the fullest in percent of total volume.
- Basic conservation releases are made on each day from all three reservoirs. Additional releases are required when the flow at Montague does not equal or exceed a prescribed target. These required releases are always made from the percent fullest reservoir.
- The priority of water use and its effects are as follows. The water supply diversion is taken first from the percent fullest reservoir. After the diversion from the reservoir has been accounted for, the Montague release is made (if necessary) from the percent fullest reservoir. The reservoir which releases to meet the flow objective at Montague can be a different reservoir than the one from which the water supply is diverted. Thus for each day, accounting for diversions and releases, the reservoir volumes are kept in balance.

The target flow at Montague and the maximum diversion allowed from the New York City reservoirs is set by the operating level of the reservoirs. The New York City reservoirs are either in normal, drought warning, or drought condition depending on the combined storage in the reservoirs each day and the time of year. Figure IV-1 shows the reservoir storage curves which defined the reservoir conditions and the maximum diversions and Montague targets for each condition developed for this study. The storage curves, diversions, and targets are a modification of the Drought Emergency Operating Rules - Model #2 for the New York Delaware System presented in the Task Group Report, DRBC Docket No. D-77-20[1].

The basic conservation releases for each reservoir vary with the season. Table IV-3 presents the basic conservation releases for the New York City reservoirs. The conservation releases are those specified in the DRBC Docket D77-20CP.

[1] Task Group Report DRBC Docket No. D-77-20 Appraisal of Upper Basin Reservoir Systems, Drought Emergency Criteria and Conservation Measures, Delaware River Basin Commission, March 1979.



	Diversion(mgd)	Montague(cfs)
Normal	800	1750
Drought Warning	600	1750
Drought	430	1525

FIGURE IV-1. Modified Drought Emergency Operating Rules-Model #2
New York Delaware System

TABLE IV-3

BASIC CONSERVATION FLOW NEEDS

Reservoir	Dates constant minimum flows must be maintained	Constant minimum flow	River in which constant minimum flow is to be maintained	Gaging station at which flow is to be measured
Cannonsville	April 16 to Nov. 30 inclusively	15 mgd (23.2 cfs)	West Branch Delaware River	Stilesville
Cannonsville	Dec. 1 to April 15 inclusively	5 mgd (7.7 cfs)	West Branch Delaware River	Stilesville
Pepacton	April 8 to Oct. 31 inclusively	12 mgd (18.6 cfs)	East Branch Delaware River	Downsville
Pepacton	Nov. 1 to April 7 inclusively	4 mgd (6.2 cfs)	East Branch Delaware River	Downsville
Neversink	April 8 to Oct. 31 inclusively	10 mgd (15.5 cfs)	Neversink River	Neversink
Neversink	Nov. 1 to April 7 inclusively	3 mgd (4.6 cfs)	Neversink River	Neversink

The operating rules for diversion and releases used in the daily flow model simulate the flow response in the basin under the conditions that all three reservoir volumes are kept in balance with diversions and releases from the percent fullest reservoir. Also, the maximum allowable diversions are withdrawn under each of the three reservoir conditions. The model approach, which evaluates the total storage available at the maximum diversion rates, is somewhat different than the actual operation of the New York City reservoirs. In the actual operation, the maximum diversions are not always withdrawn from the three reservoirs. The actual amount depends on the overall diversion schedule from the entire New York City water supply system of which the three reservoirs in the Delaware River Basin are only a part. Also, instead of withdrawing the diversions from the percent fullest reservoir and then releasing to meet the Montague objective from the percent fullest reservoir, the actual schedule is as follows. The Montague target is checked and conservation releases are made from Pepacton and Neversink reservoirs. The deficit at Montague is made up by releases from Cannonsville Reservoir. Then the New York City diversions are taken from all three reservoirs maintaining them in equal balance. The actual system also has limitations on the maximum amount of water which can be released from any one reservoir based on the outlet capacities. This restriction is not imposed on the model scheme.

MODEL SIMULATION OF RESERVOIR SYSTEM

The regulated flow model is unable to predict in advance whether the flow at Montague will be below the target flow. Therefore if the flow at Montague falls below the target on any given day, the model "backs up" two days, releases the required amount from a reservoir, and proceeds with the simulation from that day. The flow at Montague in two days may not exactly equal the target flow. The releases from the New York City reservoirs must be routed for approximately two days down to Montague. The routing procedure with a daily time step attenuates the release over at least three days. But enough water is released on one day so that the three-day average at Montague is always nearly equal to or greater than the target flow. The attenuation of the release simulates the attenuation which occurs in the real river system. Using a smaller time-step would better simulate attenuation and the daily flows in the basin, but the magnitude of additional costs would not be justified by

the increased accuracy. As the model currently works, the three-day average flow at Montague is simulated accurately.

The backup procedure is based on a simple concept. The model simply backs up two days and operates with the values of all variables at that point in time. The model makes the required release from one of the New York City Reservoirs in order to meet the target flow at Montague two days later.

Figure IV-2 shows the flow chart of the reservoir operating rules, which are used in the regulated flow model.

A review of the model output clarifies the operating rules. Figures IV-3, IV-4 and IV-5 show the percent of remaining storage in each of the three New York City reservoirs in calendar year 1953 of the simulation. The releases and withdrawals from the reservoir are modeled to maintain an equal balance of the percent reservoir storage for all three reservoirs. The computer output of the three figures show that the percent remaining storages are approximately equal for the Cannonsville, Pepacton and Neversink reservoirs. For example, in January 1953 for Cannonsville (Figure IV-3), Pepacton (Figure IV-4) and Neversink (Figure IV-5), the minimum percent storages remaining are 72.80, 71.95 and 71.42; the maximum percent storages remaining are 87.31, 86.97, and 86.36; and the mean percent storages remaining are 76.89, 76.48 and 75.43.

Figures IV-6, IV-7 and IV-8 show the total outflow from each of the three reservoirs. Basic conservation releases are always made from each reservoir, required releases to Montague are always made from the percent fullest reservoir, and spills occur when the reservoirs are full. The daily variations of releases, from low to high flows, based on the model scheme does not necessarily reflect the actual reservoir operations.

For example, conservation releases are made from each of the three reservoirs during the entire months of January and February, 1953 with no spills occurring. A check against the reservoir storages during these two months, presented in Figures IV-3, IV-4 and IV-5, show that the reservoirs are less than full. These figures also demonstrate that releases are made from the percent fullest reservoir. For 31 August 1953 a release of

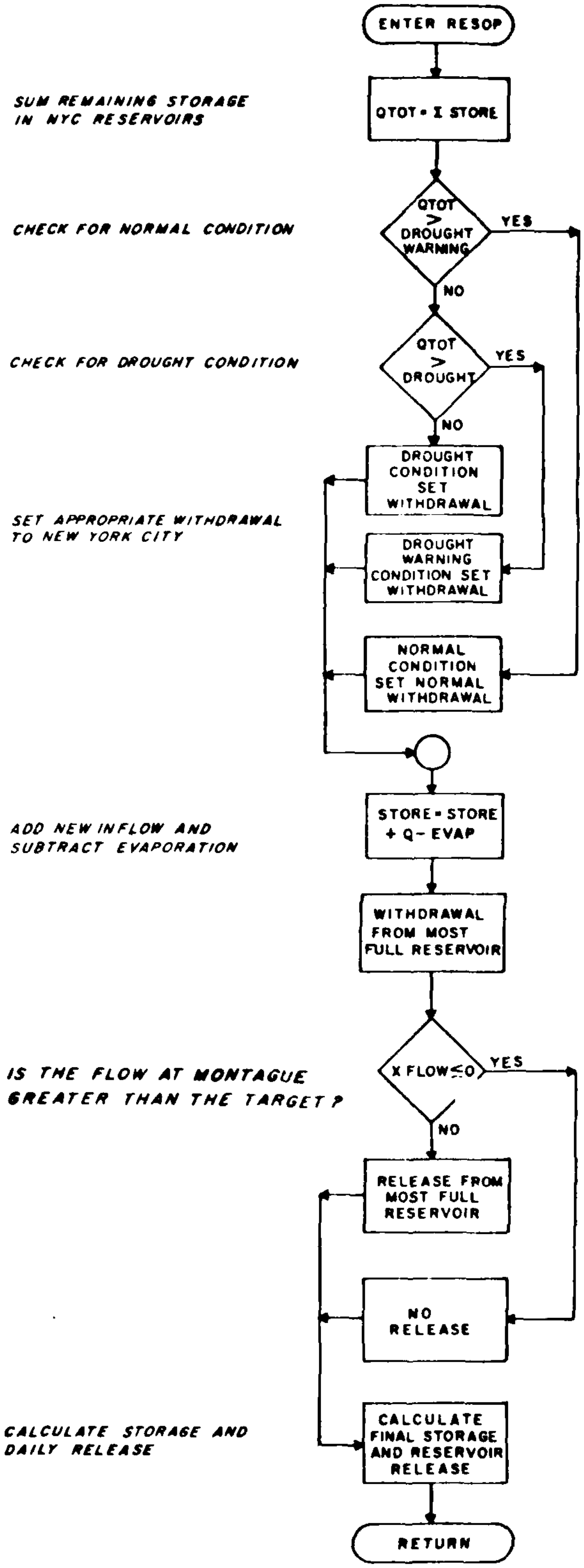


FIGURE IV-2. RESERVOIR OPERATING RULES AS EXECUTED IN THE MODEL

CDM/ WATER RESOURCES ENGINEERS
B A S E R U N
NODE 261

• • • • P H A S E I • • • •
• DELAWARE RIVER •

PHASE I BASE RUN
1953 DATA
CANNONSVILLE : PERCENT STORAGE REMAINING

------------------AVERAGE DAILY VALUES SIMULATED FOR 1953------------------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	73.94	87.52	96.77	100.00	100.00	99.77	93.49	80.81	65.61	52.24	39.65	40.58
2	74.22	88.19	97.22	100.00	100.00	100.00	92.74	80.82	64.77	51.42	39.84	40.79
3	73.66	88.04	96.81	100.00	100.00	99.40	92.82	80.26	64.78	50.65	39.71	41.17
4	73.94	87.85	97.46	100.00	100.00	99.60	92.46	79.43	63.94	50.66	39.82	40.90
5	73.33	88.34	97.45	100.00	100.00	98.97	91.68	78.61	63.12	49.84	39.34	41.31
6	73.52	88.85	98.03	100.00	100.00	99.18	91.73	77.76	63.18	49.90	38.85	41.17
7	73.70	88.54	97.70	100.00	100.00	98.57	90.95	76.93	63.62	49.51	38.62	44.08
8	73.05	89.37	98.15	100.00	100.00	98.76	90.63	76.11	63.64	49.07	38.76	45.46
9	73.23	90.19	98.56	100.00	100.00	98.08	90.70	76.11	63.25	48.38	38.27	46.25
10	72.83	90.05	98.14	100.00	100.00	98.22	90.25	76.12	62.66	47.66	38.42	47.28
11	73.47	89.81	98.48	100.00	100.00	98.34	89.65	75.72	62.77	47.76	38.58	48.62
12	73.21	90.45	98.03	100.00	99.89	97.61	88.86	74.90	61.73	47.39	38.13	49.16
13	73.68	90.19	98.52	100.00	100.00	97.73	88.90	74.07	60.98	46.63	38.30	50.30
14	73.27	90.71	98.31	100.00	100.00	97.85	88.10	73.72	61.14	46.70	37.85	50.54
15	72.82	90.40	98.94	100.00	99.98	97.12	88.14	74.11	60.41	46.07	38.03	51.20
16	73.50	90.90	99.93	100.00	100.00	97.21	88.17	73.46	59.65	45.17	38.22	51.45
17	74.44	90.52	100.00	100.00	100.00	96.45	87.36	72.74	59.72	44.39	37.81	52.32
18	74.70	90.9[illegible]	100.00	99.95	100.00	96.52	87.38	72.83	59.05	44.44	38.01	52.19
19	75.34	90.44	100.00	100.00	100.00	95.75	86.57	72.05	58.27	43.95	37.58	52.00
20	75.57	90.84	100.00	100.00	99.98	95.81	86.60	71.27	58.32	43.16	37.76	52.66
21	75.69	92.50	100.00	99.99	100.00	95.87	86.62	71.31	57.53	42.36	37.94	52.46
22	75.69	95.22	100.00	100.00	99.78	95.10	86.38	70.51	56.74	41.56	38.12	52.30
23	76.44	96.00	99.90	99.86	100.00	95.15	85.78	69.91	56.02	40.75	38.06	52.55
24	78.53	96.52	100.00	100.00	99.75	95.19	85.07	69.09	56.06	40.78	38.90	52.61
25	82.90	96.87	100.00	100.00	100.00	94.40	84.28	69.11	55.26	40.19	38.93	53.02
26	84.83	97.01	100.00	99.88	100.00	94.47	83.48	68.77	54.45	39.95	39.90	53.45
27	85.66	97.37	100.00	100.00	99.73	94.44	83.50	68.25	54.48	39.98	40.02	53.02
28	86.59	97.02	100.00	100.00	100.00	93.66	83.17	67.25	53.82	39.40	40.05	52.54
29	87.17	0.00	100.00	100.00	99.54	93.97	82.35	66.42	53.01	39.47	40.62	52.68
30	87.28	0.00	100.00	100.00	99.89	93.38	82.38	65.60	53.03	39.14	40.50	52.37
31	87.31	0.00	100.00	0.00	99.44	0.00	81.56	65.60	0.00	39.43	0.00	52.66
MIN	72.8[illegible]	87.52	96.77	99.86	99.44	93.38	81.56	65.60	53.01	39.14	37.58	40.79
MAX	87.31	97.07	100.00	100.00	100.00	100.00	93.49	80.82	65.61	52.24	40.62	53.45
MEAN	76.89	91.45	98.98	99.99	99.93	96.88	87.80	73.21	59.70	45.10	38.82	49.04
TOTAL	2383.55	2560.73	3068.40	2999.68	3097.98	2906.54	2721.76	2269.65	1791.01	1398.03	1164.58	1520.29
S DEV	5.09	3.14	1.13	.03	.14	1.98	3.41	4.42	3.84	4.18	.88	4.55

FIGURE IV-3. Percent of Remaining Available Storage in Cannonsville Reservoir for 1953

CDM/ WATER RESOURCES ENGINEERS
B A S E R U N I
NODE 26

* * * * P H A S E I * * * *
* DELAWARE RIVER *

PHASE I BASE RUN
1953 DATA
PEPACTON : PERCENT STORAGE REMAINING

--AVERAGE DAILY VALUES SIMULATED FOR 1953--

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	74.46	87.54	96.96	100.00	100.00	99.92	93.06	81.12	65.69	52.11	39.55	40.61
2	74.04	87.37	96.56	100.00	100.00	99.50	92.96	80.56	65.54	51.44	39.33	40.60
3	74.18	87.77	96.92	100.00	100.00	99.64	92.44	80.00	64.71	50.67	39.51	40.73
4	73.76	88.12	97.37	100.00	100.00	99.20	91.91	79.51	64.18	50.31	39.23	40.57
5	73.68	88.43	97.85	100.00	100.00	99.33	91.69	79.02	63.76	50.31	39.37	40.66
6	73.43	88.13	97.64	100.00	100.00	98.88	91.15	78.45	63.19	49.77	39.25	41.22
7	73.53	88.76	97.95	100.00	100.00	99.08	91.19	78.46	62.93	49.29	38.95	43.31
8	73.64	89.41	97.67	100.00	100.00	98.67	90.66	78.05	62.48	48.80	38.65	44.87
9	73.18	89.31	97.94	100.00	100.00	98.79	90.15	77.05	61.97	48.27	38.77	45.94
10	73.34	89.71	98.18	100.00	100.00	98.33	89.64	76.56	61.44	48.33	38.47	47.26
11	73.06	90.06	97.82	100.00	100.00	97.85	89.69	76.00	60.90	47.48	38.19	48.34
12	73.31	89.85	98.37	100.00	100.00	97.94	89.70	75.53	60.92	46.96	38.34	49.17
13	72.95	90.18	97.79	100.00	100.00	97.46	89.08	75.19	61.14	46.55	38.49	49.37
14	73.15	90.48	98.18	100.00	100.00	97.55	88.86	74.51	60.97	46.01	38.59	50.10
15	73.34	90.77	98.69	100.00	100.00	97.64	88.32	74.31	60.67	45.47	38.32	51.00
16	73.05	90.48	99.74	100.00	99.89	97.14	88.30	73.96	60.31	44.93	38.07	51.64
17	73.40	90.74	100.00	100.00	100.00	97.21	87.99	73.51	59.32	44.27	38.27	51.59
18	73.97	90.39	100.00	100.00	100.00	96.70	87.13	72.39	58.79	43.72	37.98	51.57
19	74.64	90.61	100.00	99.93	100.00	96.66	87.15	71.84	58.24	43.17	38.15	52.34
20	75.16	90.26	100.00	100.00	100.00	96.06	86.61	71.15	57.70	43.19	38.19	52.12
21	75.63	91.54	100.00	100.00	100.00	95.53	86.07	70.59	57.72	42.64	37.96	52.47
22	76.04	92.92	100.00	99.85	100.00	95.60	85.52	70.03	57.26	42.11	37.73	52.62
23	75.84	93.84	100.00	100.00	99.77	95.08	85.55	69.46	56.71	41.56	38.35	52.58
24	77.69	94.58	100.00	99.81	100.00	95.12	85.01	68.99	56.12	40.89	38.54	52.64
25	81.14	95.20	100.00	100.00	99.67	95.15	84.49	68.43	55.70	40.49	39.11	53.07
26	82.89	95.73	100.00	100.00	99.90	94.27	84.30	67.86	55.14	40.07	39.37	52.74
27	84.00	96.[illegible]	100.00	100.00	100.00	93.75	83.95	67.86	54.02	39.66	39.91	52.97
28	85.03	96.62	100.00	100.00	99.68	93.79	83.40	67.29	54.03	39.73	40.38	53.18
29	85.85	0.00	100.00	100.00	99.90	93.42	83.14	66.63	53.74	39.43	40.36	52.62
30	86.43	0.00	100.00	100.00	99.52	93.55	82.19	66.57	52.67	39.86	40.71	53.01
31	86.97	0.00	100.00	0.00	99.74	0.00	81.68	66.38	0.00	39.74	0.00	52.62
MIN	72.95	87.37	96.66	99.81	99.52	93.42	81.68	66.38	52.67	39.43	37.73	40.61
MAX	86.97	96.62	100.00	100.00	100.00	99.92	93.06	81.12	65.69	52.11	40.71	53.18
MEAN	76.48	90.89	98.88	99.99	99.94	96.96	87.84	73.46	59.60	45.08	38.87	48.68
TOTAL	2371.00	2545.00	3065.34	2999.67	3098.08	2908.77	2722.99	2277.26	1787.97	1397.43	1166.12	1515.42
S DEV	4.60	2.66	1.19	.04	.12	1.99	3.26	4.63	3.66	4.06	.77	4.64

FIGURE IV-4. Percent of Remaining Available Storage in Pepacton Reservoir for 1953

CDM/ WATER RESOURCES ENGINEERS
B A S E R U N T
NODE 2620

* * * * P H A S E I * * * *
* DELAWARE RIVER *
* * *

PHASE I BASE RUN
1953 DATA
NEVERSINK : PERCENT STORAGE REMAINING

--AVERAGE DAILY VALUES SIMULATED FOR 1953--

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	72.52	86.96	96.61	98.42	99.36	97.97	93.04	81.19	63.17	51.35	39.99	39.64
2	72.76	87.49	96.94	99.23	100.00	98.15	93.10	78.51	63.17	51.35	39.39	39.90
3	[illegible]	87.98	97.33	99.92	98.96	98.13	91.64	78.54	63.16	51.35	37.69	40.02
4	[illegible]	88.42	96.07	100.00	99.89	98.11	91.70	78.57	63.17	50.67	37.77	40.45
5	[illegible]	86.53	96.92	98.31	100.00	98.09	91.76	78.60	63.20	50.14	37.82	40.52
6	73.55	86.97	97.43	98.84	98.74	98.06	91.30	78.60	62.96	48.60	37.91	42.73
7	71.42	87.85	97.86	100.00	99.69	98.03	90.68	75.89	63.10	48.67	37.99	42.08
8	71.58	88.67	98.24	99.11	100.00	98.00	90.77	75.92	63.13	48.70	38.08	43.60
9	71.76	89.25	96.30	100.00	98.47	97.97	89.23	75.95	63.14	48.72	38.16	45.24
10	71.99	89.66	96.63	98.77	99.12	97.94	89.29	73.69	63.15	46.71	38.23	47.35
11	72.36	90.05	96.94	99.82	99.70	97.91	87.06	73.75	61.54	46.73	38.31	45.91
12	72.63	90.44	97.30	100.00	100.00	97.88	87.13	73.75	61.57	46.75	38.45	46.83
13	72.85	90.82	98.38	98.69	98.35	97.85	87.19	73.78	60.68	46.76	36.79	47.74
14	73.05	88.85	99.89	99.58	98.95	95.53	87.28	73.81	58.40	44.82	36.85	48.62
15	73.28	89.20	99.80	100.00	99.55	95.50	87.35	71.52	58.43	44.86	36.91	49.29
16	73.53	89.54	100.00	98.50	100.00	95.48	85.12	71.55	58.45	44.85	36.98	49.59
17	71.49	89.87	99.61	99.27	98.53	95.45	85.15	71.55	56.44	44.85	37.17	50.30
18	72.12	90.17	100.00	99.97	99.33	95.42	85.22	71.55	58.46	42.78	37.35	51.02
19	72.72	90.46	98.84	100.00	99.91	95.39	85.25	71.55	58.48	42.77	37.52	51.31
20	73.14	90.76	99.86	98.36	100.00	95.36	85.31	71.58	57.79	40.48	35.97	51.65
21	73.49	92.97	100.00	98.92	98.14	95.33	85.37	69.37	55.88	40.49	36.13	51.99
22	73.61	92.38	98.52	99.44	98.54	95.31	85.40	69.37	55.88	40.50	36.31	52.40
23	74.10	93.22	99.34	99.96	99.32	95.28	83.21	69.37	55.88	40.51	36.89	52.75
24	77.27	93.97	100.00	100.00	99.80	92.96	83.24	69.37	53.60	38.80	37.22	53.14
25	80.78	94.63	100.00	98.20	100.00	92.93	83.30	67.72	53.61	38.81	37.72	51.08
26	82.03	95.21	100.00	99.32	98.09	92.90	83.33	67.75	53.62	38.85	38.22	51.30
27	83.10	95.76	99.72	100.00	98.56	92.88	81.07	65.46	53.63	38.90	38.44	51.57
28	84.23	96.25	100.00	98.84	98.95	92.87	81.07	65.46	51.35	39.02	38.67	51.78
29	85.13	0.00	98.75	99.68	99.29	92.91	81.10	65.46	51.35	39.45	38.89	52.09
30	85.77	0.00	99.65	100.00	99.61	92.95	81.13	65.46	51.35	39.64	39.08	52.30
31	86.36	0.00	100.00	0.00	99.95	0.00	81.16	63.17	0.00	39.83	0.00	52.54
MIN	71.42	86.53	96.07	98.20	98.09	92.87	81.07	63.17	51.35	38.80	35.97	39.64
MAX	86.36	96.25	100.00	100.00	100.00	98.15	93.10	81.19	63.20	51.35	39.99	53.14
MEAN	75.43	90.51	98.61	99.37	99.32	95.95	86.58	72.19	58.66	44.41	37.76	48.02
TOTAL	2338.41	2534.30	3056.89	2981.18	3078.82	2878.55	2683.95	2237.84	1759.72	1376.71	1132.91	1488.69
S DEV	4.78	2.73	1.36	.67	.62	2.02	3.77	4.67	4.11	4.40	.93	4.49

FIGURE IV-5. Percent of Remaining Available Storage in Neversink Reservoir for 1953

CDM/ WATER RESOURCES ENGINEERS • • • • P H A S E I • • • • PHASE I BASE RUN
B A S E R U N I • DELAWARE RIVER • 1953 DATA
NODE 1610 • • • W BR DELAWARE AT STILESVILLE 01425000

----------AVERAGE DAILY VALUES SIMULATED FOR 1953----------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	7.70	7.70	7.70	2154.26	2579.18	23.20	23.20	1164.45	23.20	1218.91	23.20	7.70
2	7.70	7.70	7.70	816.42	2091.34	75.56	23.20	23.20	23.20	23.20	23.20	7.70
3	7.70	7.70	7.70	506.42	2719.18	23.20	23.20	880.27	23.20	1190.79	475.87	7.70
4	7.70	7.70	7.70	256.42	1021.34	23.20	650.56	23.20	23.20	23.20	90.95	7.70
5	7.70	7.70	7.70	1484.26	1141.34	23.20	23.20	23.20	23.20	23.20	23.20	7.70
6	7.70	7.70	7.70	46.42	2329.18	23.20	23.20	1296.41	23.20	23.20	23.20	7.70
7	7.70	7.70	7.70	836.42	631.34	23.20	23.20	23.20	23.20	995.46	543.45	7.70
8	7.70	7.70	7.70	2634.26	471.34	23.20	564.21	23.20	843.49	1029.25	23.20	7.70
9	7.70	7.70	7.7	846.42	1919.18	23.20	23.20	23.20	944.37	23.20	23.20	7.70
10	7.70	7.70	7.70	1984.26	371.34	23.20	768.03	23.20	1129.43	23.20	23.20	7.70
11	7.70	7.70	7.70	616.42	41.34	23.20	985.59	630.48	23.20	23.20	23.20	7.70
12	7.70	7.70	7.70	246.42	23.20	23.20	23.20	23.20	453.81	699.25	23.20	7.70
13	7.70	7.70	7.70	1484.26	1247.32	23.20	23.20	23.20	23.20	23.20	23.20	7.70
14	7.70	7.70	7.70	326.42	131.34	23.20	23.20	23.20	23.20	23.20	23.20	7.70
15	7.70	7.70	7.70	46.42	23.20	23.20	23.20	23.20	23.20	1047.09	23.20	7.70
16	7.70	7.70	7.70	1264.26	1397.32	23.20	23.20	23.20	23.20	1442.41	23.20	7.70
17	7.70	7.70	1415.88	26.42	1699.18	23.20	23.20	23.20	23.20	23.20	23.20	7.70
18	7.70	7.70	95.05	7.70	461.34	23.20	23.20	23.20	1112.46	23.20	23.20	7.70
19	7.70	7.70	1442.89	1182.98	171.34	23.20	23.20	1257.33	23.20	806.28	23.20	7.70
20	7.70	7.70	415.05	1254.26	23.20	23.20	23.20	23.20	23.20	1265.72	23.20	7.70
21	7.70	7.70	195.05	7.70	1017.32	23.20	23.20	23.20	23.20	23.20	23.20	7.70
22	7.70	7.70	1192.89	1122.98	23.20	23.20	410.48	1257.77	23.20	23.20	23.20	7.70
23	7.70	7.70	7.70	7.70	689.32	23.20	952.52	958.04	1160.12	1269.61	23.20	7.70
24	7.70	7.70	1420.24	787.98	23.20	23.20	1151.00	23.20	23.20	23.20	23.20	7.70
25	7.70	7.70	2542.89	936.26	326.32	23.20	23.20	23.20	23.20	23.20	23.20	7.70
26	7.70	7.70	3472.89	7.70	650.18	23.20	23.20	554.01	1274.43	417.34	23.20	7.70
27	7.70	7.70	3882.89	2122.98	23.20	225.69	23.20	819.67	23.20	23.20	23.20	7.70
28	7.70	7.70	2365.05	2134.26	314.32	23.20	555.32	1523.75	1051.01	23.20	23.20	7.70
29	7.70	0.00	2872.89	586.42	23.20	23.20	23.20	23.20	23.20	23.20	23.20	7.70
30	7.70	0.00	1175.05	326.42	23.20	23.20	23.20	23.20	23.20	23.20	23.20	7.70
31	7.70	0.00	1495.05	0.00	23.20	0.00	23.20	23.20	0.00	23.20	0.00	7.70
MIN	7.70	7.70	7.70	7.70	23.20	23.20	23.20	23.20	23.20	23.20	23.20	7.70
MAX	7.70	7.70	3882.89	2634.26	2719.18	225.69	1151.00	1523.75	1274.43	1442.41	543.45	7.70
MEAN	7.70	7.70	774.99	868.72	762.26	31.69	211.98	349.33	282.65	382.13	58.02	7.70
TOTAL	238.70	215.60	24024.66	26061.52	23630.20	950.85	6571.30	10829.38	8479.52	11846.10	1740.68	238.70
S DEV	0.00	0.00	1138.31	754.60	831.24	37.23	342.25	502.21	447.67	512.49	122.12	0.00

FIGURE IV-6. Total Outflow from Pepacton Reservoir in 1953

CDM/ WATER RESOURCES ENGINEERS
B A S E R U N I
NODE 16

* * * * P H A S E I * * * *
DELAWARE RIVER

PHASE I BASE RUN
1953 DATA
E BR DELAWARE AT DOWNSVILLE 01417000

------------------------------AVERAGE DAILY VALUES SIMULATED FOR 1953------------------------------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	6.20	6.20	6.20	1634.71	2328.05	18.60	18.60	18.60	268.57	18.60	6.20	6.20
2	6.20	6.20	6.20	1704.71	2698.05	18.60	358.21	18.60	344.48	1487.56	6.20	6.20
3	6.20	6.20	6.20	1454.71	2258.05	18.60	18.60	18.60	567.81	18.60	6.20	6.20
4	6.20	6.20	6.20	1354.71	1858.05	18.60	18.60	1100.39	1142.64	18.60	6.20	6.20
5	6.20	6.20	6.20	1264.71	2028.05	18.60	580.98	1109.38	935.38	18.60	6.20	6.20
6	6.20	6.20	6.20	1104.71	1918.05	18.60	18.60	18.60	18.60	18.60	517.48	6.20
7	6.20	6.20	6.20	1504.71	1568.05	18.60	18.60	18.60	18.60	18.60	6.20	6.20
8	6.20	6.20	6.20	1764.71	1618.05	18.60	18.60	914.53	18.60	18.60	6.20	6.20
9	6.20	6.20	6.20	1444.71	1618.05	18.60	18.60	976.50	18.60	1293.05	6.20	6.20
10	6.20	6.20	6.20	1384.71	1438.05	18.60	18.60	1089.95	18.60	18.60	6.20	6.20
11	6.20	6.20	6.20	1354.71	1228.05	18.60	18.60	18.60	18.60	701.93	6.20	6.20
12	6.20	6.20	6.20	1144.71	1068.05	18.60	78.40	1039.66	18.60	18.60	6.20	6.20
13	6.20	6.20	6.20	1164.71	1128.05	18.60	180.36	779.26	18.60	976.75	6.20	6.20
14	6.20	6.20	6.20	1244.71	1038.05	18.60	574.28	1588.04	670.79	18.60	136.54	6.20
15	6.20	6.20	6.20	1024.71	968.05	18.60	18.60	610.52	879.32	18.60	6.20	6.20
16	6.20	6.20	6.20	1104.71	18.60	18.60	120.02	851.85	957.05	18.60	6.20	6.20
17	6.20	6.20	1614.06	1194.71	989.66	18.60	731.88	1037.67	1059.07	1491.17	6.20	6.20
18	6.20	6.20	1673.18	1034.71	1208.05	18.60	682.24	1237.87	18.60	18.60	147.96	6.20
19	6.20	6.20	1613.18	18.60	1068.05	224.91	18.60	18.60	1309.13	18.60	87.40	6.20
20	6.20	6.20	1593.18	942.98	962.05	187.60	18.60	1521.05	18.60	18.60	360.66	6.20
21	6.20	6.20	1253.18	1034.71	848.05	18.60	18.60	18.60	18.60	1258.87	6.20	6.20
22	6.20	6.20	1123.18	18.60	745.05	18.60	18.60	18.60	1077.82	1196.65	6.20	6.20
23	6.20	6.20	1003.18	541.98	18.60	18.60	18.60	18.60	18.60	18.60	6.20	6.20
24	6.20	6.20	395.34	18.60	132.66	18.60	18.60	1041.34	1335.61	1482.07	6.20	6.20
25	6.20	6.20	2713.18	421.98	18.60	18.60	1181.80	18.60	976.16	935.20	6.20	6.20
26	6.20	6.20	3633.18	1234.71	18.60	773.56	475.69	18.60	18.60	18.60	6.20	6.20
27	6.20	6.20	3833.18	1276.87	474.11	18.60	805.48	18.60	1245.50	18.60	6.20	6.20
28	6.20	6.20	3103.18	2314.71	18.60	18.60	18.60	18.60	18.60	18.60	6.20	6.20
29	6.20	0.00	2453.18	1834.71	18.60	18.60	617.47	1435.72	678.35	18.60	6.20	6.20
30	6.20	0.00	2003.18	1474.71	18.60	18.60	854.11	146.59	1113.16	18.60	6.20	6.20
31	6.20	0.00	2063.18	0.00	18.60	0.00	1161.66	425.82	0.00	18.60	0.00	6.20
MIN	6.20	6.20	6.20	18.60	18.60	18.60	18.60	18.60	18.60	18.60	6.20	6.20
MAX	6.20	6.20	3833.18	2314.71	2698.05	773.56	1181.80	1588.04	1335.61	1491.17	517.48	6.20
MEAN	6.20	6.20	975.16	1162.60	1010.88	56.28	281.25	553.76	493.74	362.34	46.83	6.20
TOTAL	192.20	173.60	30227.94	34877.94	31337.23	1688.27	8718.79	17166.53	14812.24	11232.45	1405.04	192.20
S DEV	.00	.00	1198.33	521.21	784.69	141.24	365.24	553.52	499.66	555.93	112.72	.00

FIGURE IV-7. Total Outflow from Cannonsville Reservoir in 1953

CDM/ WATER RESOURCES ENGINEERS • • • • P H A S E I • • • • PHASE I BASE RUN
B A S E R U N I • DELAWARE RIVER • 1953 DATA
NODE 1621 • • • NEVERSINK RIVER AT NEVERSINK 01436000

----------AVERAGE DAILY VALUES SIMULATED FOR 1953----------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
2	4.60	4.60	4.60	15.50	389.26	15.50	15.50	15.50	15.50	15.50	86.98	4.60
3	4.60	4.60	4.60	15.50	15.50	15.50	15.50	1466.68	15.50	15.50	345.44	4.60
4	4.60	4.60	4.60	300.70	15.50	15.50	842.79	15.50	15.50	15.50	4.60	4.60
5	4.60	4.60	4.60	15.50	608.56	15.50	15.50	15.50	15.50	383.59	4.60	4.60
6	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	15.50	318.08	4.60	4.60
7	4.60	4.60	4.60	114.94	15.50	15.50	303.54	15.50	213.58	883.75	4.60	4.60
8	4.60	4.60	4.60	15.50	336.56	15.50	385.15	1496.99	15.50	15.50	4.60	4.60
9	4.60	4.60	4.60	36.18	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
10	4.60	4.60	4.60	15.50	15.5	15.50	901.96	15.50	15.50	15.50	4.60	4.60
11	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	15.50	1117.30	4.60	4.60
12	4.60	4.60	4.60	382.94	142.86	15.50	15.50	15.50	903.19	15.50	4.60	4.60
13	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
14	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	508.52	15.50	4.60	4.60
15	4.60	4.60	4.60	178.94	15.50	15.50	15.50	15.50	15.50	1068.86	4.60	4.60
16	4.60	4.60	1453.51	15.50	58.86	15.50	15.50	15.50	15.50	15.50	4.60	4.60
17	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
18	4.60	4.60	470.26	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
19	4.60	4.60	4.60	366.70	15.50	15.50	15.50	15.50	15.50	1135.91	4.60	4.60
20	4.60	4.60	4.60	15.50	238.86	15.50	15.50	15.50	15.50	15.50	4.60	4.60
21	4.60	4.60	377.51	15.50	15.50	15.50	15.50	15.50	400.61	15.50	4.60	4.60
22	4.60	4.60	4.60	15.50	15.50	15.50	15.50	1210.12	1044.45	15.50	4.60	4.60
23	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
24	4.60	4.60	2045.51	270.46	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
25	4.60	4.60	183.01	15.50	116.16	15.50	15.50	15.50	15.50	15.50	4.60	4.60
26	4.60	4.60	353.01	15.50	15.50	15.50	15.50	906.16	15.50	15.50	4.60	4.60
27	4.60	4.60	4.60	755.94	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
28	4.60	4.60	598.26	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
29	4.60	0.00	4.60	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
30	4.60	0.00	4.60	225.94	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
31	4.60	0.00	250.51	0.00	15.50	0.00	15.50	15.50	0.00	15.50	0.00	4.60
MIN	4.60	4.60	4.60	15.50	15.50	15.50	15.50	15.50	15.50	15.50	4.60	4.60
MAX	4.60	4.60	2045.51	755.94	608.56	15.50	901.96	1496.99	1044.45	1135.91	345.44	4.60
MEAN	4.60	4.60	188.33	105.27	73.00	15.50	92.00	177.37	115.26	170.81	18.71	4.60
TOTAL	142.60	128.80	5837.38	3158.24	2263.12	465.00	2851.95	5498.45	3457.85	5294.99	561.22	142.60
S DEV	.00	.00	445.06	170.51	135.61	0.00	220.59	429.14	256.83	350.67	62.45	.00

FIGURE IV-8. Total Outflow from Neversink Reservoir in 1953

425.82 cfs is made from the Pepacton Reservoir (Figure IV-7) while the Cannonsville Reservoir (IV-6) and the Neversink Reservoir (Figure IV-8) are making basic conservation releases of 23.0 cfs and 15.5 cfs respectively. For 30 August 1953, which is checked to determine the next day release from the percent fullest reservoir, the percent remaining storage of Pepacton (66.57 shown in Figure IV-4) is greater than the percent remaining storage of Cannonsville (65.60 shown in Figure IV-3) and Neversink (65.46 shown in Figure IV-5).

For certain dates these figures show that a release from Neversink occurs on the same day as a release from one of the other two reservoirs. The model is programmed to release the Neversink flow augmentation for Montague one day later than the day for which the release is calculated to occur. Because the route time from Neversink to Montague is approximately one day less than the route time of the other two reservoirs, this adjustment is made to make certain that only one release flow from any of the three reservoirs arrives at Montague on any one day.

Figure IV-9 shows the amount of water diverted to New York City. Note that in 1953 the model is in a normal condition for most of the year during which 800 mgd is diverted to New York City. During the period October 24 through December 7 the model is in a drought warning condition and 600 mgd is diverted to New York City.

The final figures in this series show the flow at Montague for the natural model (Figure IV-10) and the regulated model (Figure IV-11). Figure IV-10 shows that for many days especially during the months of July through October the natural flow at Montague is less than the Montague target used in the regulated model simulation. The regulated flow model operates to maintain the Montague target. However, Figure IV-11 shows several days which fall slightly below the target of 1750 cfs. This variation is due to the attenuation of the releases over three or more days which is built into the model. Releases are attenuated as they travel from the reservoirs to Montague. The amount of attenuation of the releases is different for each reservoir depending on the total time of travel from the reservoir to Montague. If releases are made for several

CDM/ WATER RESOURCES ENGINEERS
B A S E   R U N   1
NODE 4 1

* * * * P H A S E   I * * * *
* DELAWARE RIVER *
* * *

PHASE I BASE RUN
1953 DATA
DIVERSIONS TO NEW YORK CITY (MGD)

----------AVERAGE DAILY VALUES SIMULATED FOR 1953----------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
2	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
3	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
4	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
5	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
6	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
7	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
8	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
9	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
10	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
11	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
12	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
13	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
14	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
15	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
16	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
17	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
18	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
19	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
20	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
21	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
22	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
23	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
24	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	800.00
25	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	800.00
26	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	800.00
27	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	800.00
28	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	800.00
29	800.00	0.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	800.00
30	800.00	0.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	800.00
31	800.00	0.00	800.00	0.00	800.00	0.00	800.00	800.00	0.00	600.00	0.00	800.00
MIN	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	600.00
MAX	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	800.00
MEAN	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	748.39	600.00	754.84
TOTAL	24800.00	22400.00	24800.00	24000.00	24800.00	24000.00	24800.00	24800.00	24000.00	23200.00	18000.00	23400.00
S DEV	.00	.00	.00	.00	.00	.00	.00	.00	.00	87.51	.00	83.62

FIGURE IV-9. Average Daily Diversion (mgd) to New York City Simulated for 1953

CDM/ WATER RESOURCES ENGINEERS • • • • P H A S E 2 • • • • NATURAL FLOW SIMULATION
SPRINGFIELD, VIRGINIA • DELAWARE RIVER • OCTOBER 6,1979
NODE 2130 • • • DELAWARE RIVER AT MONTAGUE 01438311

AVERAGE DAILY DISCHARGE SIMULATED FOR 1953 (CFS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	4930.77	16497.76	18524.41	14793.17	15365.03	5772.34	3656.31	1317.41	1314.32	1212.25	3959.71	4435.29
2	4430.94	10710.65	7234.43	13692.32	21597.96	4944.38	3154.75	702.99	1414.39	779.71	3903.13	4315.34
3	4520.46	9582.68	7400.36	13304.71	19422.07	4222.70	2752.45	625.18	1453.94	592.31	2602.16	3695.66
4	4288.73	9003.30	8792.26	11133.46	17512.64	3791.18	1776.62	562.69	1444.71	526.51	2219.92	3488.15
5	4121.92	8155.92	13298.22	9591.99	15696.73	3997.01	1273.15	732.41	1295.98	501.90	1954.36	3425.66
6	4170.56	7100.37	10922.65	9582.44	19996.91	3950.49	1239.88	979.15	749.52	1496.14	2249.59	3672.14
7	3578.56	8561.41	8766.93	13434.93	16915.05	4152.91	1461.41	673.35	892.39	1518.29	2829.33	17798.39
8	3460.19	12899.35	7133.87	24036.43	15897.74	4781.65	1583.38	519.64	1927.31	1324.46	1842.59	27704.46
9	3679.27	11512.46	6744.37	19234.51	15806.78	4594.97	1515.02	536.64	3373.32	1281.57	1699.65	19081.99
10	3637.21	9406.15	6551.41	16099.12	13796.57	3731.29	1453.15	676.18	2072.97	1359.59	2734.79	15640.00
11	4882.42	8154.61	6334.07	16693.30	12534.61	3293.76	1261.46	818.95	1468.92	1224.59	2646.77	19583.08
12	6439.93	8060.13	5909.53	15709.47	10903.15	2880.77	1162.96	717.24	1113.66	859.11	2499.16	13999.29
13	6256.58	7341.18	6678.01	14099.11	10333.65	2895.93	1137.10	1357.68	1175.65	1151.31	2739.82	12997.99
14	5532.94	6991.61	7734.81	13793.14	10333.39	3022.34	1813.09	949.67	1465.94	1290.17	2671.41	13338.77
15	4991.32	6589.83	8988.61	14513.11	9785.25	3224.65	1795.19	1275.06	1850.94	1148.47	2393.13	17319.90
16	4926.29	7393.78	22535.97	12999.32	9371.24	3223.39	1491.46	993.95	1626.24	857.55	2333.08	15351.76
17	5192.82	7452.94	22377.23	14399.05	9339.46	2822.40	1874.41	1485.70	1296.59	815.93	3215.92	12973.16
18	7334.02	6774.13	16504.96	17304.45	12378.03	2661.29	1819.49	1303.91	1392.36	692.72	2990.63	9940.91
19	10692.07	6278.84	14864.51	12093.16	11937.98	2491.04	1295.76	957.00	938.70	603.75	2612.93	9337.34
20	11208.43	5967.22	16595.87	12301.80	9963.83	2372.18	1155.68	588.53	831.90	632.97	2478.72	7176.44
21	9821.26	11108.34	13719.35	11933.70	8723.09	1810.88	1969.96	591.53	837.95	943.32	2476.29	7233.69
22	9191.98	29920.59	11206.39	11104.35	8901.76	1770.58	1972.75	550.25	1289.12	814.98	2259.17	7312.75
23	8342.22	20345.36	10793.66	10003.64	7457.72	2329.64	1969.75	516.41	974.56	768.99	2857.56	7244.97
24	15395.67	15908.51	13065.01	9213.79	7853.14	2240.21	1593.19	599.19	754.67	611.77	6534.29	5338.87
25	58275.42	13322.61	27712.93	9511.33	5771.5	2159.59	1139.65	964.44	735.59	557.55	7439.84	5132.39
26	38372.43	11723.69	28059.59	8478.17	6759.	2919.72	937.95	911.33	715.16	578.19	6892.86	4569.74
27	22629.71	10800.46	30612.63	23647.34	6827.17	2409.34	867.04	932.93	755.13	752.48	7375.73	4757.13
28	18204.12	10002.58	26529.87	23391.16	6192.47	1370.95	1213.92	1119.21	611.42	1321.78	6052.52	4727.79
29	17276.24	0.00	21313.02	17515.45	5721.43	1640.95	1111.17	1109.18	757.24	2102.95	5224.77	5331.05
30	13778.56	0.00	17509.39	14596.38	5288.59	2951.53	1217.97	511.79	713.34	3924.12	4792.18	4544.93
31	11292.96	0.00	15804.43	0.00	5914.69	0.00	1317.91	509.91	0.00	4370.96	0.00	4252.94
MIN	3460.19	5967.22	5908.53	8478.17	5914.64	1370.95	867.04	506.64	611.42	501.90	1619.63	3425.65
MAX	58275.42	29920.59	30612.63	24036.43	21597.96	5772.34	3656.31	1485.70	3373.32	4370.96	7439.84	27704.46
MEAN	13695.81	10379.17	13898.20	13795.13	11349.33	3100.09	1614.02	815.55	1226.97	1172.80	3448.45	9421.44
TOTAL	350020.00	290616.64	430844.6	413583.79	351778.27	93177.76	50034.75	25266.30	36792.08	36356.70	103453.61	292064.56
S DEV	11297.62	9829.17	7237.73	3928.28	4309.57	1159.47	611.93	262.71	558.59	952.90	1732.19	5239.92

FIGURE IV-10. Natural Flow at Montague Simulated for 1953

CDM/ WATER RESOURCES ENGINEERS
B A S E R U N
NODE 1130

* * * * P H A S E I * * * *
DELAWARE RIVER

PHASE I BASE RUN
1953 DATA
DELAWARE RIVER AT MONTAGUE 01438500

--------AVERAGE DAILY VALUES SIMULATED FOR 1953--------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	3857.70	7402.04	6125.98	13327.73	13884.10	4583.10	2925.69	1779.01	1797.98	1519.77	2688.28	2603.47
2	3461.47	7815.56	5141.94	11754.03	20057.50	3800.83	2517.98	1940.06	1688.52	1982.79	1846.22	2370.63
3	3592.05	6938.19	5684.35	12189.05	18545.85	3271.04	2397.06	1606.41	1748.22	1666.95	1783.60	2192.21
4	3422.71	6739.24	7222.11	9662.73	16444.80	3044.83	1796.48	1756.56	1777.98	1861.35	1864.76	2128.19
5	3274.30	6112.72	11344.68	8221.30	14422.64	3252.91	1815.67	1690.65	1847.82	1389.12	1620.56	2171.10
6	3346.53	5272.62	8554.00	8708.95	18106.65	3339.36	1647.43	1701.25	1630.15	1701.76	1727.43	2302.16
7	2992.07	6806.11	6517.43	12304.56	15880.78	3562.69	1638.32	2014.64	1521.95	1827.52	2408.91	14847.62
8	2840.38	10530.95	5258.10	22318.82	14674.53	4144.67	1736.45	1557.82	1710.72	1973.89	1840.26	21767.29
9	3087.48	8376.96	5130.65	17963.96	14387.65	3820.72	1894.29	1561.56	2673.14	1857.13	1567.79	10934.20
10	3991.16	6336.34	5125.54	14857.04	12718.37	3164.81	1713.28	1712.86	1887.69	1672.64	2254.13	8927.47
11	4051.68	5685.24	4941.68	15621.50	11216.64	2572.48	1866.23	1716.75	1913.53	1579.05	2129.53	12285.25
12	5160.02	5991.61	4659.93	12518.75	9377.47	2436.37	1317.39	1719.50	1500.21	1612.88	1948.91	8364.99
13	4686.51	5424.33	5385.22	12713.65	8605.26	2502.82	1418.35	1761.72	1711.81	1863.55	2145.87	8250.61
14	3879.88	5049.23	6210.92	15752.20	9004.76	2650.89	1767.23	1633.89	1678.40	1719.08	2048.79	9265.48
15	3729.17	4869.47	6672.66	13365.97	8671.86	2843.85	1821.17	1895.24	1763.59	1670.70	1776.56	13451.99
16	3729.21	5770.42	19258.40	11587.76	7921.37	2840.96	1596.17	1429.43	1758.68	1962.95	1714.30	11377.44
17	3789.37	6282.30	19011.01	13082.53	8129.57	2474.64	1877.03	1765.61	1716.47	2028.04	2569.30	8259.77
18	5375.88	5290.33	13374.67	11201.82	11243.34	2359.15	1875.29	1744.19	1721.71	1567.72	2124.11	6776.53
19	7987.21	4932.65	12866.19	10683.37	10404.51	2212.84	1691.16	1746.76	1950.87	1530.79	1892.83	5783.71
20	7875.37	4737.12	15437.70	11232.28	8475.00	2170.68	1564.74	1963.34	1648.13	1828.83	1728.13	5043.10
21	6476.84	9242.98	12520.55	10915.16	7357.49	1727.37	2014.72	1646.59	1446.74	2033.65	1800.37	5207.38
22	6298.36	25062.21	9859.44	9885.27	7144.14	1703.51	1833.71	1546.27	1827.19	1585.36	1652.26	5351.21
23	5836.66	13903.91	9735.36	8931.92	6618.75	2161.99	2009.49	2008.65	1725.21	1675.41	2075.79	5306.64
24	11692.15	9074.33	11921.28	7840.43	6755.22	2020.77	2049.19	1727.82	1968.20	1979.86	5010.35	4447.48
25	48603.80	8327.32	26306.64	7261.23	5349.70	1962.37	1926.28	1636.27	1643.17	1640.08	5047.95	3424.92
26	27375.60	7883.12	26351.16	7426.02	5442.62	2051.75	1603.02	1614.54	1601.57	1535.14	4200.37	3125.33
27	12831.76	7546.93	29230.06	17128.19	5850.79	2396.35	1520.49	1763.36	2044.38	1664.98	4573.20	3447.99
28	10863.25	7170.00	25442.81	21894.27	5070.95	1629.98	1791.95	1948.24	1583.60	1612.60	3288.03	3460.51
29	11511.86	0.00	20230.93	16258.12	4565.20	1679.08	1767.53	2145.02	1867.99	1937.77	2791.59	3826.73
30	8929.84	0.00	16600.79	13204.02	3918.26	2098.55	1691.82	1524.67	1526.98	3504.37	2655.79	3419.28
31	7389.36	0.00	14597.61	0.00	3805.09	0.00	1767.92	1376.70	0.00	3467.03	0.00	3185.63
MIN	2840.38	4737.12	4659.93	7261.23	3805.09	1629.98	1418.35	1376.70	1446.74	1389.12	1567.79	2128.09
MAX	48603.80	25062.21	29230.06	22318.82	20057.50	4583.10	2925.69	2145.02	2673.14	3504.37	5047.95	21767.29
MEAN	7772.57	7663.26	12151.90	12760.42	10130.67	2682.71	1853.34	1730.17	1762.75	1862.99	2425.87	6558.35
TOTAL	240949.64	214571.24	376708.78	382812.63	314050.88	80481.34	57453.53	53635.37	52882.62	57752.76	72775.95	203308.83
S DEV	8847.50	3878.42	7285.51	3847.36	4554.19	760.68	295.49	171.99	220.37	457.15	984.56	4528.49

FIGURE IV-11. Regulated Flow at Montague Simulated for 1953

days in a row (as in August 1953), and are made from one reservoir on one day and another reservoir on the next, the discharges at Montague fluctuate about the target flow depending on how the routed releases have combined. However, the three day average of the discharges at Montague always nearly equals or exceeds the target flow as discussed previously in this chapter.

RESULTS

The question addressed in this aspect of the modelling project is, "Can the upper basin reservoirs provide enough water to meet the demands both at New York City and Montague?" As shown in the natural model results in Chapter III, the periods of concern are the droughts of the thirties and the sixties or more specifically the most critical years 1931 and 1965. The regulated flow model further substantiates the fact that the sixties drought was the most severe.

The Drought of the 1930's

To analyze the drought of the thirties, two operating rules are investigated. The first rule is the modified Drought Emergency Operating Rules-Model #2 which is discussed earlier in this report. Figures IV-12, IV-13 and IV-14 show the remaining useable storage in each of the three reservoirs in 1931 using this operating rule. The minimum daily percent remaining storage for Cannonsville (Figure IV-12) is 23.98; for Pepacton (Figure IV-13), 23.99; and for Neversink (Figure IV-14), 23.01 all of which occur during the month of February. Therefore, there is enough reservoir storage in 1931 to maintain the flow target at Montague. Figures IV-15 and IV-16 list for 1930 and 1931, respectively, the average daily diversion to New York City. Figure IV-15 shows that on November 27, 1930 the reservoir system is shifted into the Drought Warning Condition. At this time the diversion to New York City is reduced from 800 mgd to 600 mgd and the required flow at Montague remains at 1,750 cfs. Figure IV-16 shows that on January 3, 1931 the system goes into the Drought Condition. This condition provides 430 mgd to New York City and maintains 1,525 cfs at Montague.

CDM/ WATER RESOURCES ENGINEERS
BASE RUN I
NODE 2610

* * * * * P H A S E I * * * * *
DELAWARE RIVER

PHASE I BASE RUN
1930-31 DATA
CANNONSVILLE : PERCENT STORAGE REMAINING

----------AVERAGE DAILY VALUES SIMULATED FOR 1931----------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	33.15	27.29	24.77	41.80	65.23	77.94	76.65	87.00	78.75	67.97	55.42	45.42
2	33.22	26.95	24.62	43.50	65.41	77.57	76.78	86.44	78.89	68.02	54.90	45.68
3	32.83	26.56	24.91	45.06	66.20	77.96	76.08	86.71	78.99	67.24	54.71	45.65
4	32.90	26.22	24.75	46.76	66.27	77.46	76.16	86.20	78.31	67.28	54.51	44.45
5	32.98	25.74	25.02	48.39	66.23	76.91	75.44	86.45	78.43	67.16	54.13	44.62
6	32.62	25.34	24.83	49.75	66.12	77.17	75.55	85.82	78.23	66.79	53.61	44.31
7	32.74	25.40	24.65	50.99	65.95	77.42	75.72	85.99	78.19	66.54	53.09	44.56
8	32.75	25.45	24.94	52.17	66.52	76.97	76.33	85.30	77.99	66.06	52.78	44.76
9	32.57	25.23	24.81	53.41	67.14	77.36	76.35	85.48	76.95	65.56	52.40	44.12
10	32.33	24.83	25.10	54.77	67.43	77.68	76.50	84.96	76.17	64.80	51.77	44.42
11	32.12	24.89	24.94	57.27	68.36	78.05	79.86	85.17	75.93	64.23	51.43	44.00
12	31.83	24.71	25.24	59.38	68.84	77.51	81.11	84.52	75.98	63.73	51.08	44.49
13	31.50	24.64	25.08	60.54	69.84	77.76	81.51	84.73	75.83	62.93	50.44	44.33
14	31.08	24.45	24.90	61.25	70.27	77.98	82.40	84.80	75.45	62.97	50.10	45.60
15	30.67	24.10	25.19	61.76	70.61	77.33	82.23	84.65	74.40	62.65	50.08	46.52
16	30.72	24.23	25.02	62.10	71.40	77.54	82.04	83.96	73.63	62.23	49.49	46.75
17	30.43	23.98	25.30	62.28	72.37	78.20	82.57	83.25	73.77	61.48	48.93	46.76
18	30.04	24.25	25.16	62.37	72.30	77.94	82.18	83.37	73.16	61.18	49.15	46.63
19	30.10	24.19	25.50	62.35	72.09	78.34	82.59	83.42	73.28	60.57	49.09	46.38
20	29.72	24.11	25.39	62.27	72.62	77.86	82.12	82.70	72.54	59.79	48.78	46.52
21	29.35	24.48	25.30	62.12	72.79	78.32	82.87	82.79	72.17	59.84	48.48	46.56
22	29.41	24.83	25.81	61.94	73.69	77.86	85.68	82.03	71.43	59.22	48.58	47.04
23	29.02	24.69	26.04	61.89	73.64	78.16	87.41	82.10	71.53	58.43	47.74	46.69
24	28.68	24.56	26.63	62.70	74.74	77.61	88.05	81.63	70.77	57.63	47.06	46.67
25	28.56	24.43	27.86	62.68	75.41	77.87	88.33	80.86	70.85	57.30	46.36	47.35
26	28.63	24.75	29.65	63.25	76.75	78.09	88.36	80.91	70.10	57.33	46.49	47.11
27	28.25	24.61	31.68	63.30	77.36	77.60	88.19	80.15	69.35	56.52	46.62	47.53
28	27.88	24.46	33.77	63.98	77.64	77.83	87.89	80.40	69.44	56.55	46.47	47.12
29	27.94	0.00	36.57	64.42	77.65	77.18	87.51	79.77	68.68	55.75	45.75	47.55
30	27.62	0.00	39.14	64.94	77.52	77.34	87.14	79.90	68.75	55.86	45.93	47.11
31	27.23	0.00	40.62	0.00	77.37	0.00	86.69	79.49	0.00	55.62	0.00	47.46
MIN	27.23	23.98	24.62	41.80	65.23	76.91	75.44	79.49	68.68	55.62	45.75	44.00
MAX	33.22	27.29	40.62	64.94	77.65	78.34	88.36	87.00	78.99	68.02	55.42	47.55
MEAN	30.61	24.98	27.20	57.65	71.15	77.69	81.88	83.58	74.26	61.91	50.18	45.95
TOTAL	948.94	699.39	843.17	1729.39	2205.77	2330.79	2538.27	2590.94	2227.90	1919.21	1505.37	1424.57
S DEV	1.91	.85	4.34	6.92	4.20	.37	4.62	2.29	3.36	4.09	2.95	1.20

FIGURE IV-12. Percent of Remaining Usable Storage in Cannonsville Reservoir for 1931 under modified Operating Rules #2 (95.7 BG Total Storage)

CDM/ WATER RESOURCES ENGINEERS
B A S E R U N 1
NODE 26 0

* * * * P H A S E I * * * *
DELAWARE RIVER

PHASE I BASE RUN
1930-31 DATA
PEPACTON : PERCENT STORAGE REMAINING

--AVERAGE DAILY VALUES SIMULATED FOR 1931--

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	33.56	26.96	24.73	34.78	62.85	77.31	76.98	86.89	79.38	68.29	55.20	45.54
2	33.37	27.01	24.84	36.05	63.37	77.58	76.50	87.03	78.85	68.03	54.68	45.65
3	33.26	26.75	24.65	37.18	63.87	77.23	76.58	86.61	78.35	67.51	54.16	45.74
4	33.00	26.49	24.76	38.45	64.31	77.42	76.09	86.77	78.42	66.96	53.63	45.61
5	32.75	26.23	24.56	39.73	64.79	77.60	76.16	86.33	77.91	66.40	53.19	45.18
6	32.81	25.99	24.66	40.79	65.04	77.18	76.23	86.44	77.95	65.85	53.14	45.29
7	32.55	25.73	24.76	41.82	65.36	77.33	75.73	85.95	77.42	65.29	52.60	45.12
8	32.32	25.35	24.57	42.73	65.83	77.80	75.46	85.92	76.88	65.32	52.07	44.63
9	32.04	25.40	24.73	43.72	66.73	77.53	75.76	85.43	76.91	64.77	51.54	44.70
10	32.08	25.25	24.87	45.09	67.36	77.85	77.01	85.51	76.60	64.21	51.00	44.27
11	31.82	24.76	25.00	47.46	68.07	77.62	79.59	85.02	76.05	63.66	51.04	44.44
12	31.56	24.50	24.80	49.41	68.86	77.89	80.92	85.11	75.59	63.10	50.50	44.10
13	31.30	24.25	24.91	50.67	69.53	78.11	81.67	84.63	75.04	62.76	49.97	44.43
14	31.34	24.30	25.02	51.74	70.24	77.74	81.64	84.13	74.49	62.20	49.45	44.47
15	31.08	24.36	24.83	52.69	70.95	77.93	82.04	83.63	74.51	62.21	48.92	45.25
16	30.53	24.11	24.96	53.47	70.95	77.55	82.45	83.73	74.43	61.66	49.00	45.79
17	30.26	24.19	25.08	54.12	71.61	77.95	82.21	83.80	74.31	61.11	49.01	46.21
18	30.03	23.99	25.23	54.71	72.15	78.25	82.48	83.29	74.20	60.56	49.09	46.55
19	29.77	24.16	25.09	55.24	72.60	77.91	82.19	82.77	73.32	60.01	48.60	46.65
20	29.56	24.31	25.26	55.71	72.42	78.11	82.43	82.82	73.14	59.74	48.10	46.54
21	29.63	24.13	25.42	56.15	72.91	77.79	82.11	82.29	72.60	59.18	47.59	46.78
22	29.50	24.25	25.33	56.57	72.81	78.00	83.60	82.33	72.26	59.19	47.66	46.43
23	29.26	24.37	25.57	57.24	73.31	77.61	84.45	81.79	71.92	58.69	47.72	46.72
24	29.00	24.48	25.93	58.04	73.80	77.78	85.16	81.25	71.70	58.21	47.57	46.59
25	28.73	24.60	26.51	58.64	74.34	77.93	85.67	81.16	70.79	57.65	47.42	47.31
26	28.62	24.40	27.29	59.24	75.19	77.50	86.07	80.62	70.40	57.39	46.91	47.61
27	28.48	24.51	28.25	60.08	75.83	77.69	86.38	80.62	70.21	57.32	46.39	47.27
28	28.24	24.62	29.37	60.75	76.37	77.26	86.65	80.25	69.85	56.49	45.87	47.52
29	27.77	0.00	31.32	61.51	76.80	77.37	86.87	80.36	69.51	56.41	45.92	47.19
30	27.51	0.00	32.97	62.26	77.17	76.90	87.11	79.86	68.56	55.67	45.41	47.41
31	27.22	0.00	33.96	0.00	77.56	0.00	87.31	79.34	0.00	55.14	0.00	47.03
MIN	27.22	23.99	24.56	34.78	62.85	76.90	75.46	79.34	68.56	55.14	45.41	44.10
MAX	33.56	27.01	33.96	62.26	77.56	78.25	87.31	87.03	79.38	68.29	55.20	47.61
MEAN	30.61	24.98	26.10	50.53	70.42	77.66	81.34	83.60	74.39	61.64	49.77	45.96
TOTAL	948.92	699.45	809.22	1516.05	2182.88	2329.71	2521.52	2591.67	2231.59	1910.96	1493.23	1424.62
S DEV	1.87	.94	2.45	8.32	4.45	.31	3.99	2.36	3.06	3.87	2.77	1.09

FIGURE IV-13. Percent of Remaining Usable Storage in Pepacton Reservoir for 1931 under modified Operating Rule #2 (140.2 BG Total Storage)

CDM/ WATER RESOURCES ENGINEERS * * * * PHASE I * * * * PHASE I BASE RUN
BASE RUN I * DELAWARE RIVER * 1930-31 DATA
NODE 26? * * * NEVERSINK : PERCENT STORAGE REMAINING

------AVERAGE DAILY VALUES SIMULATED FOR 1931------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	32.57	26.57	23.58	38.00	65.06	76.36	77.08	81.96	79.82	67.23	52.39	45.74
2	30.95	25.43	23.76	39.61	65.59	76.73	77.01	82.06	79.49	64.97	52.48	43.60
3	31.05	25.53	23.92	40.98	64.38	77.03	75.93	82.17	78.93	65.00	52.57	43.73
4	31.15	25.63	24.08	42.43	64.86	77.31	76.05	82.28	78.47	65.03	52.66	43.85
5	31.26	25.72	24.26	43.85	65.30	77.56	76.17	82.40	77.30	65.06	52.73	44.00
6	31.37	25.82	24.42	44.97	65.72	77.84	74.01	82.50	75.09	65.09	50.51	44.16
7	31.52	24.83	24.58	46.13	66.14	75.85	74.18	82.59	75.15	65.11	50.58	42.01
8	31.63	24.92	24.76	47.25	65.38	77.27	74.35	82.67	75.21	62.86	50.65	42.14
9	31.74	23.78	24.96	48.29	67.02	78.00	74.54	82.75	75.27	62.91	50.71	42.25
10	30.60	23.87	23.92	49.51	68.15	76.96	75.40	82.83	75.31	62.95	50.78	42.38
11	30.70	23.96	24.10	51.29	68.00	77.88	77.16	82.91	75.36	62.98	48.56	42.55
12	30.80	24.04	24.28	52.77	69.46	78.51	77.87	83.02	73.11	63.02	48.63	42.78
13	30.91	24.13	24.45	53.79	68.89	76.72	78.28	83.14	73.15	63.04	48.71	43.15
14	29.79	23.01	24.61	54.88	69.90	77.15	78.58	83.25	73.18	61.90	48.78	43.77
15	29.88	23.10	24.81	55.84	70.91	77.52	78.84	83.34	73.21	59.64	48.86	44.49
16	29.97	23.21	25.03	56.66	71.66	77.91	79.07	83.49	73.25	59.68	48.95	44.96
17	30.06	23.35	24.01	57.41	70.21	76.21	79.30	83.60	71.02	59.72	49.06	45.31
18	30.16	23.56	24.25	58.10	70.90	76.63	79.50	83.19	71.11	59.76	46.88	45.60
19	29.70	23.94	24.53	58.82	71.48	76.95	79.73	83.26	71.19	59.79	46.98	45.66
20	29.80	24.26	24.82	59.48	72.00	77.23	79.93	82.94	71.25	59.84	47.07	46.09
21	29.03	24.52	25.07	60.15	72.58	77.50	80.12	82.46	71.31	58.58	47.16	46.31
22	27.90	23.52	25.43	60.81	73.21	77.76	80.41	80.91	71.37	56.34	44.96	46.52
23	27.98	23.73	25.84	62.53	73.96	77.99	80.69	80.97	69.15	56.39	45.05	46.81
24	28.07	23.94	26.40	62.35	72.32	78.22	80.90	81.02	69.20	56.44	45.13	47.15
25	28.16	24.13	27.21	63.23	72.88	76.13	81.08	81.07	69.24	56.49	45.21	45.23
26	27.02	24.31	28.24	62.44	73.53	76.33	81.23	80.53	69.29	54.25	45.28	45.58
27	27.12	24.48	29.57	63.87	74.06	76.55	81.37	80.58	69.34	54.29	45.35	45.65
28	27.23	24.64	30.90	63.03	74.50	76.72	81.50	80.70	67.10	54.34	45.43	46.08
29	27.32	0.00	33.66	63.79	74.88	76.87	81.62	79.80	67.15	54.40	45.50	46.29
30	27.42	0.00	35.72	64.48	75.26	77.00	81.74	79.89	67.19	54.48	45.59	46.51
31	27.51	0.00	36.93	0.00	75.90	0.00	81.86	79.96	0.00	54.57	0.00	46.70
MIN	27.02	23.01	23.58	38.00	64.38	75.85	74.01	79.80	67.10	54.25	44.96	42.01
MAX	32.57	26.57	36.93	64.48	75.90	78.51	81.86	83.60	79.82	67.23	52.73	47.15
MEAN	29.69	24.36	26.20	54.22	70.13	77.16	78.56	82.07	72.87	60.20	48.44	44.76
TOTAL	920.37	681.94	812.18	1626.74	2174.08	2314.70	2435.51	2544.23	2186.22	1866.16	1453.19	1387.44
S DEV	1.63	.90	3.47	8.12	3.54	.66	2.48	1.15	3.63	4.03	2.64	1.57

FIGURE IV-14. Percent of Remaining Usable Storage in Neversink Reservoir for 1931 under modified Operating Rules #2 (34.9 BG Total Storage)

COM/ WATER RESOURCES ENGINEERS
B A S E R U N I
NODE 40 1

* * * * P H A S E I * * * *
* DELAWARE RIVER *

PHASE I BASE RUN
1930-31 DATA
DIVERSIONS TO NEW YORK CITY (MGD)

--AVERAGE DAILY VALUES SIMULATED FOR 1930--

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
2	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
3	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
4	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
5	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
6	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
7	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
8	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
9	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
10	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
11	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
12	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
13	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
14	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
15	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
16	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
17	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
18	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
19	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
20	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
21	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
22	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
23	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
24	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
25	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
26	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
27	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
28	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
29	800.00	0.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
30	800.00	0.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00
31	800.00	0.00	800.00	0.00	800.00	0.00	800.00	800.00	0.00	800.00	0.00	600.00
MIN	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00	600.00	600.00
MAX	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	600.00
MEAN	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	773.33	600.00
TOTAL	24800.00	22400.00	24800.00	24000.00	24800.00	24000.00	24800.00	24800.00	24000.00	24800.00	23200.00	18600.00
S DEV	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	67.99	.00

FIGURE IV-15. Average Daily Diversion to New York City
for 1930 under modified Operating Rules #2

COM/ WATER RESOURCES ENGINEERS
P A G E R U N I
NODE 4 1

* * * * P H A S E I * * * *
* DELAWARE RIVER *
* * *

PHASE I BASE RUN
1930-31 DATA
DIVERSIONS TO NEW YORK CITY (MGD)

--------------------AVERAGE DAILY VALUES SIMULATED FOR 1931--------------------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	600.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
2	600.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
3	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
4	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
5	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
6	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
7	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
8	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
9	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
10	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
11	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
12	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
13	430.00	430.00	430.00	600.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
14	430.00	430.00	430.00	600.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
15	430.00	430.00	430.00	600.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
16	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
17	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
18	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
19	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
20	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
21	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
22	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
23	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
24	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
25	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
26	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
27	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
28	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
29	430.00	0.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
30	430.00	0.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
31	430.00	0.00	430.00	0.00	800.00	0.00	800.00	800.00	0.00	800.00	0.00	800.00
MIN	430.00	430.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
MAX	600.00	430.00	430.00	600.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
MEAN	440.97	430.00	430.00	532.00	703.23	800.00	800.00	800.00	800.00	800.00	800.00	800.00
TOTAL	13670.00	12040.00	13330.00	15960.00	21800.00	24000.00	24800.00	24800.00	24000.00	24800.00	24000.00	24800.00
S DEV	41.76	.00	.00	83.28	99.95	.00	.00	.00	.00	.00	.00	.00

FIGURE IV-16. Average Daily Diversion to New York City for 1931 under modified Operating Rules #2

A second set of operating rules is also tested for the thirties. This second case always provides 800 mgd to New York City and also maintains 1,750 cfs at Montague at all times. These conditions are those established in the 1954 Supreme Court Decree[1].

It should be noted that the model is designed to guarantee the required flow to both places. Thus, to preserve continuity the storages of the reservoirs are allowed to become negative if not enough water is available for both places. The advantage of this approach is that the user can determine the amount of additional storage required to overcome any deficiency.

The 1954 Supreme Court Decree conditions are tested with the equal drawdown of the New York City reservoirs. That is, the diversions and releases are taken from the percent fullest reservoir. When the reservoirs are drawndown evenly, the minimum reservoir storage during the 1930's drought is about 26 billion gallons (9.5 percent of total useable storage). There is enough storage remaining after meeting the 1954 Supreme Court Decree conditions to provide an additional diversion of 39 mgd to New York City during the 1930's drought. Therefore, with equal drawdown of the New York City reservoirs, the maximum diversion rate of the 1930's drought is 839 mgd with a 1,750 cfs flow objective at Montague. This result compares favorably with the results of the River Master[2] and the DRBC (855 mgd and 848 mgd, respectively) presented in the DRBC Task Group Report DRBC Docket No. D-77-20[3]. The maximum diversion rate of 839 is estimated with a daily flow model, and with the attenuation of reservoir releases to Montague. The River Master and DRBC's results are estimated with no attenuation of releases to Montague, and with a monthly analysis for some periods. The River Master and DRBC also estimated flows at Montague and inflows to Pepacton, Cannonsville, and Neversink Reservoirs with correlations to

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1 United States Supreme Court Decree, New Jersey v. New York, 347 U.S. 995 (1954), Approved by the United States Supreme Court June 7, 1954.

2 Office of the Delaware River Master, U.S. Geological Survey National Center, Reston, Virginia.

3 Task Group Report DRBC Docket No. D-77-20, Appraisal of Upper Basin Reservoir Systems, Drought Emergency Criteria and Conservation Measures, Delaware River Basin Commission, March 1979.

different USGS stations than in the regulated flow model. The variation between results is no surprise when all of the above factors are considered.

The Drought of the 1960's

The regulated model operates to provide the water required for the New York City diversion and for the Montague target allowing the reservoir storages to go negative. During November of 1965, the worst year of the 1960's drought, the modeled reservoir storages are barely negative. Thus, the actual reservoir storages are almost able to provide enough water for the New York City diversion and the target flow at Montague with the modified Drought Emergency Operating Rules-Model #2 and equal drawdown. Figures IV-17, IV-18 and IV-19 present the percent storage remaining in 1965 for Cannonsville, Pepacton and Neversink Reservoirs, respectively. For the month of November, the minimum daily percent storage remaining for Cannonsville is -1.68 (Figure IV-17); for Pepacton, -1.78 (Figure IV-18); and for Neversink, -2.74 (Figure IV-19). November 1965 is the only month in the sixties drought at which time the New York City diversion and the Montague flow target cannot be met. During this month and the other months of 1965 the reservoir system is operating under the drought conditions of the modified Drought Emergency Operating Rules-Model #2. The Montague target under the drought condition is 1525 cfs. The diversion from the New York City reservoirs is 430 mgd which is shown in Figure IV-20, Average Daily Diversions to New York City for 1965 under Modified Operating Rules #2. These and other outputs indicate that the reservoir system had been in a drought condition for over one year before the reservoir emptied.

The 1954 Supreme Court Decree Rules are also tested with even drawdown during the 1960's drought, and as expected, the 800 mgd diversion and 1,750 cfs Montague flow objective cannot be maintained with the current New York City reservoir storage. The critical period of the 1960's drought was June 1964 through November 1965. If the reservoirs were full on June 1964, the maximum rate of diversion which could be sustained during the critical period is 466 mgd. The River Master and the City of New York computed maximum rates of diversion for

CDM/ WATER RESOURCES ENGINEERS
BASE RUN I
NODE 261

• • • • P H A S E I • • • • •
• DELAWARE RIVER •
• • •

PHASE I BASE RUN
1965 DATA
CANNONSVILLE : PERCENT STORAGE REMAINING

AVERAGE DAILY VALUES SIMULATED FOR 1965

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	4.25	4.79	16.26	18.89	37.11	36.69	28.21	17.96	8.40	2.85	1.51	4.30
2	4.01	4.87	16.17	18.73	37.23	36.92	28.21	17.72	8.43	3.06	1.15	4.01
3	4.23	4.49	16.52	19.10	37.35	37.14	27.70	17.18	8.01	3.18	.76	3.72
4	4.03	4.65	16.42	18.98	37.39	37.16	27.32	16.60	7.61	3.30	.84	3.38
5	4.37	4.81	16.53	16.85	37.81	36.95	26.66	16.63	7.63	3.20	.50	3.03
6	4.17	4.58	16.59	19.30	37.78	36.95	26.71	16.06	7.53	3.11	.14	3.14
7	4.42	4.61	17.04	19.41	37.82	36.53	26.18	15.56	7.10	3.20	.23	2.80
8	4.64	8.71	17.05	19.53	37.79	36.18	25.73	15.58	7.11	2.95	-.12	2.35
9	4.87	10.81	17.16	19.85	38.21	35.76	25.33	15.20	6.68	3.17	-.41	2.35
10	5.53	11.91	17.67	20.04	38.18	35.86	24.89	15.19	6.32	3.37	-.69	2.35
11	5.55	13.11	17.68	20.73	38.08	35.33	24.91	14.74	6.33	3.56	-.55	2.41
12	5.52	14.24	17.63	21.51	38.05	34.96	24.47	14.33	6.18	3.35	-.92	2.46
13	5.52	15.31	18.03	22.62	38.32	34.96	24.06	13.85	6.14	3.60	-1.24	2.24
14	5.69	15.91	17.98	23.50	38.14	34.43	23.63	13.41	5.81	3.80	-1.10	2.67
15	5.66	16.24	17.88	24.29	37.96	34.12	23.13	13.02	5.33	3.91	-1.37	2.79
16	5.35	16.54	18.23	25.45	38.39	33.74	23.15	12.62	4.91	4.00	-1.68	2.51
17	5.52	16.85	18.13	26.80	38.19	33.13	22.71	12.65	4.81	3.95	-1.31	2.57
18	5.72	16.96	17.99	27.78	38.46	32.68	22.17	12.24	4.38	3.39	-1.37	3.03
19	5.56	16.99	18.35	28.92	38.29	32.22	22.20	11.80	4.40	3.52	-1.08	3.09
20	5.31	16.82	18.32	30.12	38.03	32.30	21.78	11.81	3.98	3.20	-1.18	2.65
21	5.64	16.72	18.11	31.03	38.30	32.25	21.76	11.83	3.99	2.85	-.83	2.53
22	5.13	16.73	18.44	32.02	38.42	31.63	21.32	11.38	3.89	2.98	-.64	2.53
23	5.29	16.49	18.27	32.88	38.12	31.67	20.70	11.38	3.90	2.66	-.72	2.47
24	5.37	16.34	18.60	33.47	38.31	31.21	20.09	11.08	3.50	2.77	4.42	2.41
25	5.57	16.52	18.44	33.86	37.99	30.72	19.67	10.47	3.64	2.47	4.38	2.59
26	5.30	16.69	18.41	34.72	38.05	30.36	19.23	10.05	3.79	2.62	4.34	2.71
27	5.48	16.50	18.70	35.36	37.79	29.60	18.80	9.92	3.44	2.25	4.39	2.54
28	5.15	16.41	18.49	35.85	37.91	29.14	18.80	9.94	3.11	2.37	4.63	2.60
29	5.22	0.00	18.82	36.20	37.55	28.67	18.84	9.57	3.10	2.09	4.66	2.60
30	4.94	0.00	18.77	36.92	37.15	28.72	18.13	9.13	3.20	1.73	4.64	2.60
31	5.11	0.00	18.56	0.00	37.09	0.00	18.24	8.87	0.00	1.42	0.00	2.66
MIN	4.01	4.49	16.17	18.73	37.09	28.67	18.13	8.87	3.10	1.42	-1.68	2.24
MAX	5.72	16.99	18.82	36.92	38.46	37.16	28.21	17.96	8.43	4.00	4.66	4.30
MEAN	5.10	12.71	17.78	26.23	37.91	33.60	23.06	13.15	5.42	3.03	.71	2.80
TOTAL	158.09	355.81	551.17	786.89	1175.17	1007.99	714.74	407.77	162.62	93.90	21.18	86.68
S DEV	.54	5.91	.81	6.48	.40	2.73	3.12	2.66	1.73	.61	2.23	.48

FIGURE IV-17. Remaining Usable Storage in Cannonsville Reservoir for 1965 under modified Operating Rules #2

CDM/ WATER RESOURCES ENGINEERS
P A S E R U N I
NODE 26

* * * * P H A S E I * * * *
* DELAWARE RIVER *
* * *

PHASE I BASE RUN
1965 DATA
PEPACTON : PERCENT STORAGE REMAINING

--------AVERAGE DAILY VALUES SIMULATED FOR 1965--------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	3.81	4.94	15.59	18.56	34.62	37.30	28.35	17.65	8.61	3.21	1.44	1.17
2	4.02	4.71	15.77	18.67	34.98	37.15	27.93	17.42	8.34	3.44	1.23	1.41
3	4.21	4.77	15.94	18.81	35.30	36.94	27.67	17.11	8.06	3.28	.94	1.66
4	4.35	4.83	16.13	18.93	35.62	36.69	27.11	17.11	7.76	3.30	.76	1.96
5	4.23	4.64	16.42	19.06	35.89	36.75	27.19	16.42	7.46	3.11	.50	2.13
6	4.39	4.70	16.71	18.92	36.13	36.50	26.30	16.12	7.17	3.21	.19	2.35
7	4.23	5.06	16.67	19.12	36.48	36.53	25.99	15.82	7.00	3.04	-.08	2.51
8	4.40	6.55	16.96	19.33	36.76	36.34	25.60	15.58	6.71	3.25	.00	2.69
9	4.78	7.74	17.23	19.56	37.01	36.08	25.61	15.35	6.73	3.42	-.19	2.54
10	5.03	8.61	17.18	19.84	37.27	35.70	25.31	15.11	6.43	3.27	-.40	2.71
11	5.26	9.39	17.42	20.26	37.49	35.43	24.63	14.85	6.12	3.43	-.54	2.57
12	5.49	10.25	17.63	21.00	37.70	35.11	24.32	14.53	5.84	3.63	-.79	2.45
13	5.70	10.98	17.54	21.82	37.89	34.82	23.91	14.24	5.59	3.48	-1.13	2.72
14	5.51	11.52	17.74	22.50	38.06	34.53	23.93	14.24	5.31	3.62	-1.30	3.01
15	5.61	12.03	17.93	23.31	38.22	34.17	23.62	13.99	5.33	3.78	-1.53	2.98
16	5.74	12.46	17.82	24.25	38.09	33.84	23.29	13.65	5.09	3.60	-1.63	2.94
17	5.56	12.83	18.02	25.08	38.29	33.55	23.02	13.33	4.84	3.41	-1.71	3.19
18	5.38	13.19	18.18	25.96	38.45	33.57	22.72	13.02	4.61	3.52	-1.60	3.12
19	5.50	13.42	18.07	26.84	38.59	33.24	22.02	12.72	4.54	3.43	-1.78	3.13
20	5.62	13.65	18.22	27.70	38.68	32.76	21.72	12.43	4.45	3.32	-1.63	3.21
21	5.43	13.89	18.37	28.49	38.42	32.18	21.41	11.70	3.96	3.20	-1.46	3.07
22	5.56	14.09	18.22	29.32	38.48	31.89	21.10	11.41	3.97	3.18	-1.22	3.26
23	5.38	14.25	18.39	30.09	38.52	31.61	20.80	11.02	3.68	3.23	-.98	3.11
24	5.48	14.44	18.25	30.71	38.29	31.22	20.50	10.72	3.94	2.91	-.76	3.01
25	5.28	14.77	18.41	31.29	38.37	30.74	20.50	10.42	3.85	2.83	-.55	3.10
26	5.40	15.03	18.58	32.01	38.14	30.27	20.14	10.12	3.84	2.79	-.31	3.36
27	5.19	15.22	18.41	32.67	38.00	29.96	19.70	9.83	3.69	2.68	.03	3.61
28	5.27	15.40	18.56	33.23	37.80	29.97	19.35	9.51	3.45	2.20	.36	3.58
29	5.03	0.00	18.42	33.74	37.55	29.55	18.69	9.21	3.22	2.26	.63	3.53
30	5.10	0.00	18.57	34.21	37.25	28.80	18.37	8.83	2.94	1.99	.91	3.50
31	4.86	0.00	18.71	0.00	37.29	0.00	17.94	8.86	0.00	1.75	0.00	3.78
MIN	3.81	4.64	15.59	18.56	34.62	28.80	17.94	8.83	2.94	1.75	-1.78	1.17
MAX	5.74	15.40	18.71	34.21	38.68	37.30	28.35	17.65	8.61	3.78	1.44	3.78
MEAN	5.06	10.48	17.62	24.84	37.41	33.77	23.19	13.30	5.42	3.12	-.42	2.81
TOTAL	156.79	293.35	546.07	745.27	1159.64	1013.19	718.78	412.32	162.51	96.76	-12.58	87.21
S DEV	.56	3.93	.91	5.44	1.13	2.58	2.99	2.71	1.64	.48	.96	.63

FIGURE IV-18. Remaining Usable Storage in Pepacton Reservoir for 1965 under modified Operating Rules #2

CDM/ WATER RESOURCES ENGINEERS
BASE RUN I
NODE 26??

* * * * P H A S E I * * * *
DELAWARE RIVER

PHASE I BASE RUN
1965 DATA
NEVERSINK : PERCENT STORAGE REMAINING

------AVERAGE DAILY VALUES SIMULATED FOR 1965------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	3.84	4.67	16.06	18.86	36.15	35.65	27.94	16.53	8.49	3.48	-.16	1.66
2	4.24	4.78	16.32	19.00	36.69	36.01	26.75	16.69	7.47	3.19	.01	1.56
3	3.20	4.89	15.31	17.89	37.05	36.20	26.80	16.74	7.71	3.70	.18	2.30
4	3.54	3.75	15.47	18.05	37.50	36.34	26.84	15.54	7.84	2.93	-.84	2.72
5	3.84	2.63	15.66	18.23	36.65	35.18	25.65	15.56	6.93	3.29	-.69	3.05
6	4.10	2.72	15.65	18.53	36.99	35.29	25.68	15.57	7.03	2.38	-.53	2.14
7	4.35	4.52	15.64	18.92	37.54	35.40	25.74	15.60	7.10	2.92	-1.56	2.38
8	4.64	7.56	15.76	19.30	37.94	35.53	25.76	14.85	6.71	3.88	-1.40	2.67
9	5.01	9.67	15.93	19.81	37.10	35.60	24.22	15.40	6.38	3.20	-1.18	2.93
10	4.07	9.48	16.10	20.47	37.56	34.44	24.27	14.05	6.47	3.66	-1.61	1.52
11	4.57	10.48	16.28	20.11	37.88	34.50	24.27	14.14	4.55	2.86	-2.02	2.21
12	4.84	11.10	16.43	21.61	38.21	34.57	24.29	14.21	4.61	3.33	-1.68	2.45
13	5.06	11.68	16.42	21.42	37.27	33.27	24.30	14.27	4.76	3.70	-1.66	3.14
14	5.22	12.02	16.44	22.27	37.44	33.43	22.99	12.64	4.89	2.83	-2.74	2.44
15	4.07	12.45	16.67	24.03	37.74	33.49	23.01	12.67	3.79	1.99	-2.56	2.67
16	4.24	12.90	16.77	26.01	38.05	33.52	21.80	12.71	3.90	2.27	-2.26	3.26
17	4.43	13.28	16.93	26.05	38.34	33.60	21.92	11.54	4.01	2.50	-1.83	2.25
18	4.50	13.63	17.24	27.06	37.33	31.68	21.95	11.67	4.12	2.78	-1.52	2.64
19	4.76	13.88	17.40	27.93	37.54	31.76	21.99	11.83	3.00	1.81	-1.32	2.53
20	4.90	14.11	17.40	28.84	37.72	31.81	21.97	10.66	3.09	2.05	-1.15	3.15
21	5.05	14.45	17.39	29.79	37.92	31.86	20.48	10.74	3.18	2.28	-2.18	3.38
22	5.24	14.67	17.57	30.92	36.87	31.91	20.52	10.81	2.03	1.36	-1.77	2.42
23	5.43	14.90	17.65	31.87	36.97	29.80	20.52	9.62	2.14	1.71	-1.41	2.70
24	4.32	15.14	17.67	32.53	37.16	29.84	20.54	9.66	2.62	1.94	-1.13	2.55
25	4.49	15.58	17.71	33.25	37.30	29.89	18.87	9.73	3.04	2.15	-.90	4.00
26	4.65	15.81	17.81	34.21	37.41	29.91	18.88	9.84	2.04	1.16	-.63	3.28
27	4.76	15.83	17.81	35.03	37.58	29.92	18.90	9.94	2.22	1.36	.06	2.01
28	4.90	15.81	17.80	35.68	36.48	27.83	17.67	9.03	2.39	1.58	.55	3.04
29	5.02	0.00	18.15	36.26	36.58	27.88	17.68	9.03	1.34	.54	.96	3.42
30	4.46	0.00	18.41	35.61	36.66	27.92	17.71	9.08	1.53	.73	1.33	3.79
31	4.54	0.00	18.67	0.00	35.55	0.00	16.50	7.96	0.00	.90	0.00	2.90
MIN	3.28	2.63	15.31	17.89	35.55	27.83	16.50	7.96	1.34	.54	-2.74	1.66
MAX	5.43	15.83	18.67	36.26	38.34	36.34	27.94	16.74	8.49	3.88	1.33	4.00
MEAN	4.53	10.76	16.86	25.65	37.26	32.80	22.47	12.52	4.51	2.40	-1.04	2.77
TOTAL	140.46	301.39	522.51	769.54	1155.16	984.04	696.43	388.27	135.38	74.46	-31.22	85.76
S DEV	.50	4.44	.95	6.38	.61	2.63	3.13	2.66	2.14	.93	.99	.53

FIGURE IV-19. Remaining Usable Storage in Neversink Reservoir for 1965 under modified Operating Rules #2

COMZ WATER [illegible] INFLOWS
A [illegible]
MODE 4 1

* * * * * [illegible] * * * * *
DELAWARE RIVER

PHASE I BASE RUN
1965 DATA
DIVERSIONS TO NEW YORK CITY (MGD)

----------AVERAGE DAILY VALUES SIMULATED FOR 1965----------

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
2	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
3	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
4	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
5	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
6	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
7	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
8	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
9	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
10	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
11	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
12	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
13	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
14	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
15	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
16	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
17	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
18	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
19	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
20	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
21	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
22	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
23	430.00	430.	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
24	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
25	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
26	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
27	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
28	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
29	430.00	0.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
30	430.00	[illegible]	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
31	430.00	0.00	430.00	0.00	430.00	0.00	430.00	430.00	0.00	430.00	[illegible]	430.00
MIN	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
MAX	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
MEAN	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00	430.00
TOTAL	[illegible]	12040.	13330.00	12900.00	13330.00	12900.00	13330.00	13330.00	12900.00	13330.00	12900.00	13330.00
S DEV	[illegible]	[illegible]	.00	.00	[illegible]	.00	.00	.00	.00	.00	.00	.00

FIGURE IV-20. Average Daily Diversion to New York City for 1965 under Modified Operating Rules #2

this period of 482 and 482.3 mgd, respectively[1]. Both the River Master and New York City assumed no attenuation of the releases made to Montague, which accounts for the slight discrepancy in results.

DURATION AND FREQUENCY ANALYSIS

Flow duration and low flow frequency analyses are performed on the simulated 50 years of regulated daily flows for 44 key locations which were also analyzed for the naturalized flows. The U.S. Geological Survey's Daily Values Statistics Program (A969) as described in Chapter III, is used to perform the analysis. For the regulated flow simulation the A969 program was run by the Philadelphia Corps of Engineers at Boeing Computer Service in Vienna, Virginia. The tables and frequency plots of the regulated daily flows are given in Appendix B.

The duration tables for each location are given on Table B-1 of Appendix B. The flow values equaled or exceeded for nine percentages are displayed in the duration table. Reservoir regulation of the flows causes a variation of the frequency curves from those which were produced by the naturalized flows. The duration curves are presented in Figures A-1 to A-44 in Appendix A. The curves are plotted on the same graph as the naturalized flow duration curves.

On the mainstem of the Delaware River below the reservoirs, the regulation of flow causes the higher flows of naturalized conditions to be dampened out and reduced. It also increases the lower naturalized flow as flow requirements at Montague are being met by releases from the reservoirs. Figures A-5, A-14, A-29, A-44 of Appendix A demonstrate this fact for the locations at Callicoon, Montague, Trenton, and the Delaware Memorial Bridge at Wilmington, Delaware, respectively. The square symbols on the Figures represent the natural duration curves for these locations and the circular symbols represent the regulated duration curves.

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[1]Task Group Report DRBC Docket No. D-77-20, Appraisal of Upper Basin Reservoir Systems, Drought Emergency Criteria and Conservation Measures, Delaware River Basin Commission, March 1979.

For each of the 44 key location Log-Pearson low flow frequency tables are produced for periods of 1, 3, 7, 14, 30, 60, 90, 120, 183 and 365 consecutive days. The regulated low flow frequency results are given in Tables B-2.1 through B-2.44 in Appendix B. In each table the low flows for each of the ten consecutive day periods are given for eleven recurrence intervals and the corresponding probabilities.

The Log-Pearson distribution is a cumulative probability distribution determined from the base-10 logarithms of the sample observations. These observations are the low 1 day, 7 day, etc. for each of the years analyzed. Because of the regulation of flows to meet the flow requirements at Montague the lowest flows for the 50-year period are similar in magnitude for the 60, 90, 120 and 183 consecutive day periods for all the mainstem locations below the reservoirs. For example the lowest 90-day flow for the 50-year period at Montague is 1520 cfs, the lowest 120-day flow is 1530 cfs, and the lowest 183-day flow is 1530 cfs.

For several locations on the mainstem below the reservoirs the calculated low flow frequency values at the lower probabilities do not consistently increase with the increasing number of consecutive days as should be expected. For example, in some cases the 120-day flow for the 100 year recurrence interval is calculated to be less than the 90-day flow for the 100 year recurrence interval. This is a result of the Log-Pearson distribution fit through the sample data in which the lowest flows are similar for each of these two consecutive day periods but the higher flows of the 120 day period are greater than the high flows for the 90 day period. This causes the frequency curve for the 120 day period to actually fall below the frequency curve for the 90 day period. Whenever these inconsistencies occurred, the flows are plotted against duration on log-log paper for the particular probability. Adjustments are made so that low flow always increases with duration.

Regulated low flow frequency curves for the 7-day and 120-day periods are shown in Figures B-1 through B-18 in Appendix B for the 18 key locations given in Table IV-4. The square symbols on the figures represent the 7-day frequency curves and the circular symbols represent the 120-day frequency curves. The frequency curves of the natural flows, given in Appendix A show a wider variation of the flows for given recurrence intervals than do the frequency curves at locations where regulation occurs. The flows for the 7-day and 120-day periods for the regulated flows are similar in magnitude during low flow conditions due to the flow regulation by the reservoirs to maintain higher flows in the Delaware River during dry weather periods.

TABLE IV-4

KEY LOCATIONS FOR LOW FLOW
FREQUENCY CURVES

Location	USGS Station
East Branch Delaware River at Downsville, NY	01417000
West Branch Delaware River at Stilesville, NY	01425000
West Branch Delaware River at Hale Eddy, NY	01426500
Delaware River near Callicoon, NY	01427405
Delaware River near Barryville, NY	01428500
Lackawaxen River at Hawley, PA	01431500
Delaware River at Port Jervis, NY	01434000
Neversink River at Neversink, NY	01436000
Delaware River at Montague, NJ	01438500
Pohopoco Creek at Beltzville Damsite, PA.	01449800
Lehigh River at Bethlehem, PA	01453000
Tohickon Creek at Pipersville, PA	01459500
Delaware River at Trenton, NJ	01463500
Tulpehocken Creek at Blue Marsh Damsite, PA.	01470960
Schuylkill River at Reading, PA	01471500
Schuylkill River at Philadelphia, PA	01474500
Delaware River below Mouth of Schuylkill	None
Delaware River at Delaware Memorial Bridge	None

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VOLUME II

PHASE II REPORT
FOR
DEVELOPMENT OF A DAILY FLOW MODEL
OF THE DELAWARE RIVER
WHICH INCORPORATES
RESERVOIR SYSTEMS ANALYSIS

VOLUME II

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I. INTRODUCTION

The purpose of Phase II is to analyze various reservoir combinations in the Delaware River Basin, used specifically to supplement the flow of the Delaware River at Trenton, New Jersey during low flow conditions. Combinations include both proposed and existing reservoirs, with modifications to some of the existing reservoirs' operating rules. The following reservoirs are systematically analyzed for augmenting low flow at Trenton: Beltzville, FE Walter, Prompton, Nockamixon, and Hackettstown. Two other reservoirs, Merrill Creek and Cannonsville with a modified storage, are also analyzed even though they do not release directly to maintain the Trenton flow. Table I-1 lists all the reservoirs involved in the analysis along with pertinent information of each: location, USGS gaging station, drainage area and usable storage. All other reservoirs in the basin are operated as they have been in the past. The New York City reservoirs of Pepacton, Cannonsville and Neversink are operated according to specified operating rules discussed in Chapter II.

With reservoirs on line, additional storage and modifications to operating rules become an increased regulated supply of water which will undoubtedly improve the low flow characteristics of the basin. The question addressed here is which reservoir combinations are more beneficial than others. Table I-2 gives the 17 reservoir combinations analyzed in Phase II. The analysis tests the ability of each combination to sustain a maximum low flow objective at Trenton for a series of historical hydrologic conditions such as the worst event in the past 50 years and an average event in the same 50 years. Note that any combination, which includes Prompton, routes Prompton's releases around Montague, using a methodology which at the same time gives Montague credit for Prompton's natural inflow. A detailed discussion is given in Chapter III.

The maximum low flow objective is achieved when the total usable storage of the reservoirs as given in Table I-1 is depleted with no consideration of reservoir or release water quality. Each reservoir does maintain a minimum pool level that is not considered a part of the usable storage.

TABLE I-1

RESERVOIR INFORMATION

Reservoir	Location	USGS Gaging Station	Drainage Area (sq.mi.)	Usable Storage (BG)
[1]Cannonsville (modified)	West Branch Delaware River at Stilesville, N.Y.	01425000	456	108.8
Prompton	Lackawaxen River at Prompton, PA	01429000	59.7	10.1
[1]Merrill Creek	Off-Channel Delaware River near Belvidere	none	none	15.0
FE Walter	Lehigh River near White Haven, PA	01447800	290	22.8
Beltzville	Pohopoco Creek near Parryville, PA draining into Lehigh River	01449800	109	13.0
Hackettstown	Musconetcong River at Hackettstown, N.J.	01456000	70.0	9.9
Nockamixon	Tohickon Creek at Pipersville, PA draining into the Delaware River	01459500	97.4	13.0
[1,2]Blue Marsh	Tulpehocken Creek at Blue Marsh Damsite, PA	01470960	175	7.5[3] (4/1-9/30) 5.7[3] (10/1-3/31)

[1]Not used to maintain specific Trenton flow

[2]Used only in the Total Basin Model

[3]Includes dead storage

TABLE I-2

RESERVOIR COMBINATIONS

COMBINATION	RESERVOIRS
1	Beltzville (13.0)[1] Cannonsville existing
2	Beltzville (13.0) Cannonsville modified
3	Beltzville (35.8) Cannonsville modified FE Walter modified
4	Beltzville (13.0) Cannonsville modified Merrill Creek
5	Beltzville (23.1) Cannonsville modified Prompton modified[2]
6	Beltzville (26.0) Cannonsville modified Nockamixon
7	Beltzville (35.8) Cannonsville modified FE Walter modified Merrill Creek
8	Beltzville (45.9) Cannonsville modified FE Walter modified Prompton modified[2]
9	Beltzville (48.8) Cannonsville modified FE Walter modified Nockamixon
10	Beltzville (23.1) Cannonsville modified Merrill Creek Prompton modified[2]
11	Beltzville (26.0) Cannonsville modified Merrill Creek Nockamixon
12	Beltzville (36.1) Cannonsville modified Prompton modified[2] Nockamixon
13	Beltzville (45.9) Cannonsville modified FE Walter modified Merrill Creek Prompton modified[2]
14	Beltzville (48.8) Cannonsville modified FE Walter modified Merrill Creek Nockamixon
15	Beltzville (58.9) Cannonsville modified FE Walter modified Merrill Creek Prompton modified[2] Nockamixon
16	Beltzville (58.7) Cannonsville modified FE Walter modified Merrill Creek Nockamixon Hackettstown
17	Beltzville (68.8) Cannonsville modified FE Walter modified Merrill Creek Prompton modified[2] Nockamixon Hackettstown

[1]Storage contributing to maintain Trenton flow in BG does not include Cannonsville or Merrill Creek

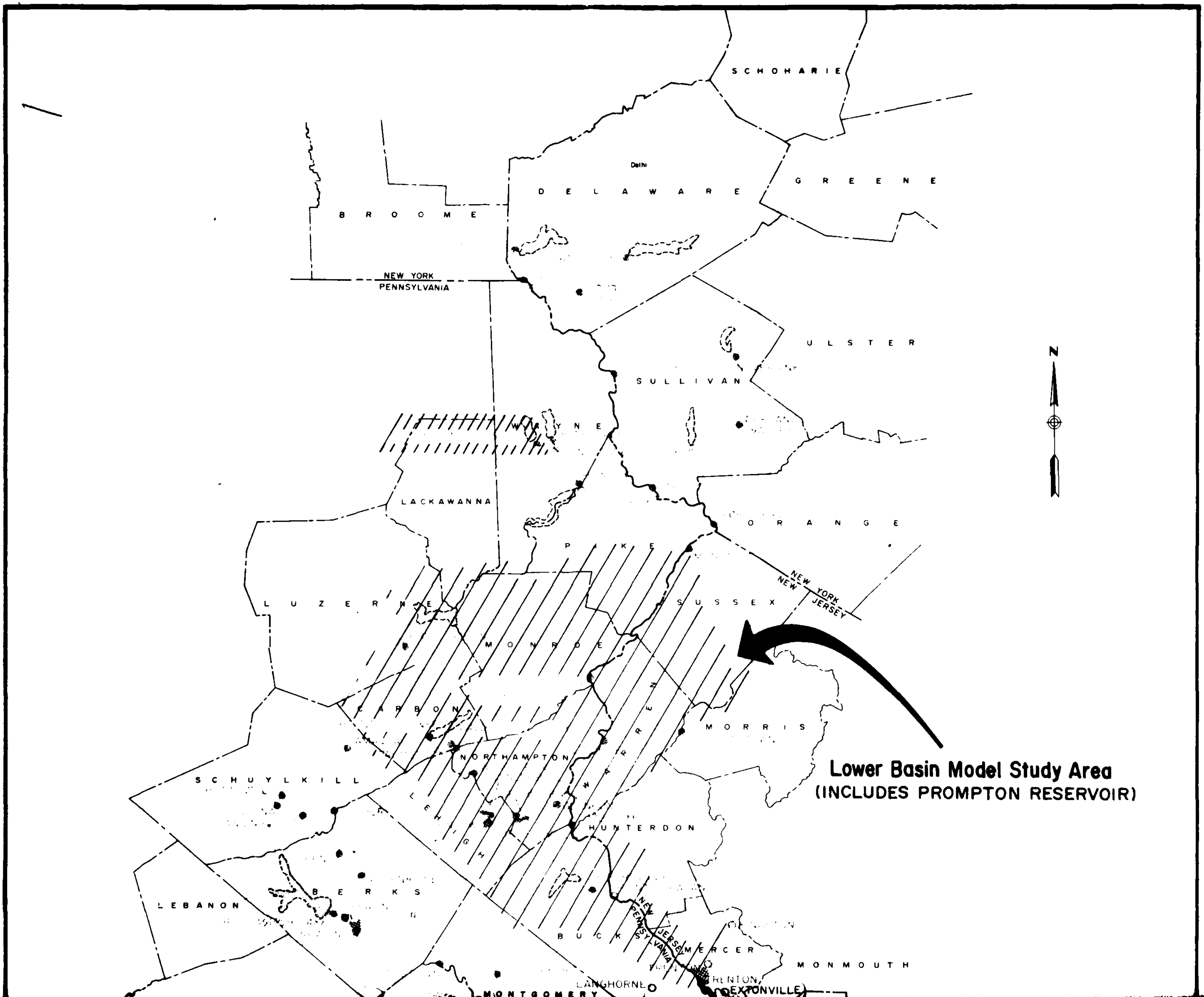
[2]Uses a routing scheme around Montague

The Phase II analysis is separated into three major categories: base run, reservoir combinations and total basin modeling. Each preceding category is an essential step to the next category.

The first step consists of a base run which sets the general basin conditions for the reservoir combinations analysis. This base run emphasizes the differences bet· :en Phase I and Phase II. It encompasses future conditions such as consumptive uses based on a year 2000 projection, plus the augmented conservation releases from the New York City reservoirs of Pepacton, Cannonsville, and Neversink. The Delaware and Raritan (D&R) Canal is specifically operated rather than using historic diversions. Phase II uses a diversion scheme for the D&R Canal based on the same system conditions as used for the New York City reservoirs.

The second step is the use of the Lower Basin Model for the reservoir analysis as described in Chapter III. Unlike the Total Basin Model, this model has a reduced study area. Montague's 50-year flow, already prescribed by the previous Base Run, used in order to keep the New York City reservoirs' operations constant, creates the "headwaters" to the Lower Basin Model at Montague. This also eliminates the backup procedure used to operate the New York City reservoirs. The study area is further reduced by running the model only as far as Trenton, the node whose flow governs the operation of the lower basin reservoirs. Figure I-1 presents pictorially the difference of the basin study area between the two models. The Lower Basin Model considers the middle portion of the basin with Montague acting as its headwaters and Trenton as the end of the system. The Total Basin Model uses the basin in each simulation from the headwaters to the Delaware Memorial Bridge at Wilmington, Delaware.

Several of the combinations treat Prompton as a source for meeting the flow objectives at Trenton. Because Prompton is upstream of Montague, a special consideration of the Montague "headwaters" is made. Briefly, the Prompton inflows are subtracted from the Montague flow after the New York City reservoirs have completed their operations. Then the Lower Basin Model treats the Prompton Reservoir as another node flowing into the Delaware River at Montague. For more detail, see the discussion in Chapter III.



SCHOHARIE
DELAWARE
Delhi
GREENE
BROOME
NEW YORK
PENNSYLVANIA
ULSTER
SULLIVAN
WAYNE
LACKAWANNA
ORANGE
PIKE
LUZERNE
SUSSEX
NEW YORK
NEW JERSEY
MONROE
CARBON
MORRIS
NORTHAMPTON
WARREN
SCHUYLKILL
LEHIGH
HUNTERDON
BERKS
LEBANON
BUCKS
NEW JERSEY
PENNSYLVANIA
MERCER
MONMOUTH
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TRENTON
EXTONVILLE
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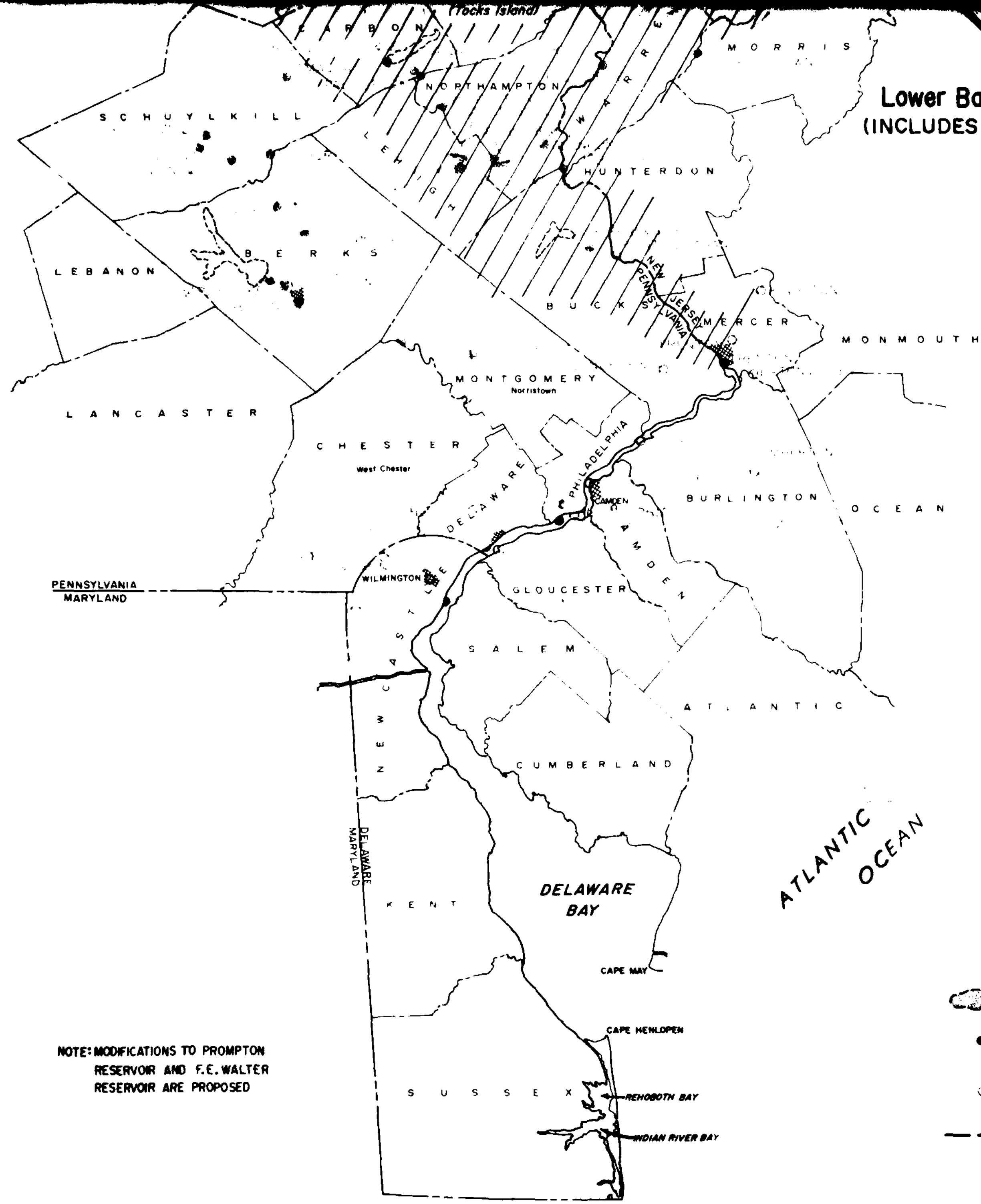
N
Lower Basin Model Study Area
(INCLUDES PROMPTON RESERVOIR)

Lower Basin Model Study Area
(INCLUDES PROMPTON RESERVOIR)



NOTE: MODIFICATIONS TO PROMPTON RESERVOIR AND F.E. WALTER RESERVOIR ARE PROPOSED

LEGEND

- PROPOSED RESERVOIR
- EXISTING RESERVOIR
- KEY LOCATIONS (NODES) FOR DURATION AND FREQUENCY ANALYSIS
- ADDITIONAL NODES FOR THE DAILY FLOW MODEL
- DELAWARE RIVER BASIN BOUNDARY

DAILY FLOW MODEL

LOCATION OF NODES FOR DURATION AND FLOW ANALYSIS

DELAWARE RIVER BASIN
SEPTEMBER 1980

2

The Total Basin Modelling, or third step, ties the reservoir analysis done with the Lower Basin Model to the total basin study area (Chapter IV). The worst event's maximum sustainable Trenton objective is used in all of the total basin simulations. Using the Total Basin Model, two separate modelling analyses are performed.

The first total basin modelling analysis deals directly with the Prompton Reservoir releases and its affects on both the New York City reservoir releases and the lower basin reservoir releases. For this analysis, Beltzville and FE Walter are on line to augment the Trenton flow as well as Prompton. This is Combination 8 from Table I-1. Three cases are tested in this category. The first alternative keeps the New York City reservoirs releasing the same amount as the Base Run by not allowing the Prompton release to augment the Montague flow. This is done by changing the Montague target whenever the Prompton outflow is different from the natural inflow. This is referred to as "Prompton *Around* Montague" and is discussed more fully in Chapter IV. The second alternative allows the Prompton releases to help augment the Montague flow while being operated by the Trenton flow. This is called "Prompton *Through* Montague." The New York City reservoirs' operating rules are identical for each of these two simulations. The third and last alternative has a different set of operating rules for the New York City reservoirs to compare with the second alternative. In all three cases, the Trenton flow objective is held constant to the worst event maximum objective obtained from the lower basin reservoir analysis.

The second analysis compares the results from the total basin runs for Beltzville only (Combination One) and all reservoirs on line (Combination 17) to the results from the Phase II Base Run. Duration and low flow frequency analyses for these three cases are presented in Chapter IV.

II. BASE RUN PHASE II

The base run conditions for Phase II differ from the Phase I base run. The differences are due to changes in the Phase II base run to reflect the addition of augmented conservation releases required by the Delaware River Basin Commission for Pepacton, Cannonsville and Neversink; projected consumptive uses for the year 2000; and specified Delaware and Raritan (D & R) Canal diversions.

The New York City reservoir operating rules remained the same in Phase II as Phase I. Table II-1 gives the operation matrices used for both Phase I and II. The Montague objectives and New York City diversions are identical. The conservation releases are the same for each reservoir for the system conditions of Drought Warning and Drought. However, in the Normal Condition, augmented releases are made from each reservoir in Phase II while in Phase I it is again the basic conservation release. In Phase II, future projections of the D&R Canal diversions are made whereas in Phase I, the historical diversions were used. The consumptive use increases in the Basin from 1975 to 2000 are incorporated in Phase II. Phase I has the consumptive uses already accounted for in the incremental inflow.

CONSERVATION RELEASES

The basic conservation releases used in Phase I have been updated to include augmented releases during Normal conditions. These additional releases help to enhance the flow conditions of the rivers downstream of the reservoirs. They are required by the New York State Department of Environmental Conservation and have been agreed upon by the Delaware River Basin Commission (DRBC). Table II-1 presents the difference between the Phase I and II conservation release schedule. Table II-2 gives the releases specified by the DRBC Docket No. D-77-20 for the New York City reservoirs.

TABLE II-1

OPERATIONS MATRICES

PHASE I

	Normal	Drought Warning	Drought
Montague (cfs)	1750	1750	1525
NYC Diversion (mgd)	800	600	430
D&R Canal (cfs)	Actual historic record		
Conservation Release*	Basic	Basic	Basic
Consumptive Uses	Actual historic accounting		

PHASE II

	Normal	Drought Warning	Drought
Montague (cfs)	1750	1750	1525
NYC Diversion (mgd)	800	600	430
D&R Canal (cfs)	155	124	93
Conservation Release*	Augmented	Basic	Basic
Consumptive Uses	Incremental increase 2000-1975 - See Table II-4		

*See Table II-3

Source: Task Group Report DRBC Docket No. D-77-20, Appraisal of Upper Basin Reservoir Systems. Drought Emergency Criteria and Conservation Measures, Delaware River Basin Commission, March 1979.

TABLE II-2

NYC RESERVOIRS RELEASE SCHEDULE AS SPECIFIED IN DRBC DOCKET D-77-20*

Reservoir	Operation Dates	Basic Conservation
Neversink	4/8 - 10/31	15.5 cfs
	11/1 - 4/7	4.6
Pepacton	4/8 - 10/31	18.5
	11/1 - 4/7	6.2
Cannonsville	4/16 - 10/31	23.2
	12/1 - 3/15	7.7
		Augmented Release
Neversink	4/1 - 10/31	45 cfs
	11/1 - 3/31	25
Pepacton	4/1 - 10/31	70
	11/1 - 3/31	50
Cannonsville	4/1 - 6/14	45
	6/15 - 8/15	325
	8/16 - 10/31	45
	11/1 - 3/31	33

*Task Group Report DRBC Docket No. D-77-20 Appraisal of Upper Basin Reservoir Systems, Drought Emergency Criteria and Conservation Measures, Delaware River Basin Commission, March 1979

Because of programming constraints, these releases are input into the model on a monthly basis as seen in Table II-3 and not on a daily basis (Table II-2) which would be required to simulate the exact changes which occur within a month. For the basic conservation releases, the monthly input uses the maximum release required for that particular month for Neversink and Pepacton. Cannonsville uses the lower release to offset the higher releases of the other two reservoirs. For the augmented releases, Neversink and Pepacton already follow a monthly schedule in Table II-2. Cannonsville does not. For the months of June and August, the larger of the two releases for Cannonsville are made for the entire month. These two simplifications are analyzed to determine the extent of the effects of modelling the monthly releases rather than the daily releases.

An analysis is performed outside the model to show the differences between the two release schedules, daily and modified monthly. For the Drought condition releases, the month in question is April. The other months are identical to the DRBC specified release schedules. The model releases 41.8 cfs from all three reservoirs. From Table II-2, the week of April 1-7 should release 18.5 cfs. This total difference is 23.3 cfs. For the week of April 8-15, the DRBC Docket states that the total should be 41.8 cfs and for the last two weeks, the total release should be 57.3 cfs, 15.5 cfs more than in the model. For the entire month of April, a total of 69.4 cfs-days will not be released in the model, or an average of 2.3 cfs per day. By the time this gets routed down to Montague, the difference is negligible.

There is, however, a rather large flow difference for the augmented Cannonsville release: 325 cfs in the model versus 45 cfs in the Docket at the beginning of June and the end of August. This increased release will drop Cannonsville into the Drought Warning Condition from the Normal Condition two weeks faster than normally expected. This would then reduce the conservation release from the augmented release of 325 cfs to the basic release of only 23.2 cfs instead of releasing 45 cfs for the next two weeks. It should be noted that these releases only affect the immediate downstream reach. However, the operation of Cannonsville in conjunction with the other two reservoirs adequately models the flows at Montague.

TABLE II-3

MODEL INPUT

CONSERVATION RELEASES
BASIC AND PROPOSED AUGMENTED
(cfs)

Reservoir	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reservoir Storage
PEPACTON													
Basic	6.2	6.2	6.2	18.6	18.6	18.6	18.6	18.6	18.6	18.6	6.2	6.2	140,190 mg
Augmented	50.0	50.0	50.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	50.0	50.0	
CANNONSVILLE													
Basic	7.7	7.7	7.7	7.7	23.2	23.2	23.2	23.2	23.2	23.2	23.2	7.7	95,706 mg
Augmented	33.0	33.0	33.0	45.0	45.0	325.0	325.0	325.0	45.0	45.0	23.0	23.0	
NEVERSINK													
Basic	4.6	4.6	4.6	15.5	15.5	15.5	15.5	15.5	15.5	15.5	4.6	4.6	34,941 mg
Augmented	25.0	25.0	25.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	25.0	25.0	

Source: Recommendation of New York State Department of Environmental Conservation

CONSUMPTIVE USES

Because Phase II is dealing with proposed conservation releases, modification to existing reservoirs and the construction of new reservoirs, it is necessary to include all other future considerations, particularly consumptive uses. Through the technique of subtracting upstream flow from downstream flow to achieve the incremental inflows, the historical consumptive uses have already been accounted for. Therefore, only the increased consumptive use is considered. The year 2000 is chosen for the baseline future consumptive uses and 1975 as the end of the historical accounting. The appropriate consumptive use increases are supplied by the Delaware River Basin Commission (DRBC) at specified nodes in the model in cfs. Table II-4 shows the consumptive uses, broken down by node and whether it is a power plant consumptive use or some other type of consumptive use.

The power plant separation was done in order to isolate the contribution of Merrill Creek Reservoir to the Delaware's flow. The design of Merrill Creek is such that when it is in operation, specific power plants' uses will be replaced by the Merrill Creek Reservoir releases. These power plants are scattered throughout the basin and are listed in Table II-4. A more detailed discussion is presented in Chapter III.

D&R CANAL DIVERSIONS

The final change from Phase I to Phase II is the operation of the Delaware and Raritan Canal. In the Phase I modelling the historical diversions are used. Phase II uses the proposed diversions of the canal. These diversions are specified by DRBC. The proposed diversions are a function of the system conditions based on the New York City reservoir storage levels. When the reservoirs are in a Normal condition, the diversion from the Delaware River into the canal is 155 cfs. The diversions for the Drought Warning and Drought conditions are 124 cfs and 93 cfs respectively as presented in Table II-1.

TABLE II-4

CONSUMPTIVE USES[1]
NET INCREASE
(CFS)
1975-2000

Node	Power Plant	All Other	Total
Port Jervis	--	1.95	1.95
Riegelsville	9.02[2]	62.56	71.58
Pt. Pleasant	70.5[3]	--	70.50
Trenton	--	30.39	30.39
Chester	26.9[4]	--	26.90[5]
Mouth of Schuylkill	--	187.3	187.30[5]
Delaware Memorial Bridge	--	71.98	71.98[5]
TOTAL	106.42	354.18	460.60

[1]Delaware River Basin Commission's Level B Study

[2]Electric Generating Station Martins Creek #3 and #4

[3]Electric Generating Stations Gilbert #8 and #9 and Limerick #1 and #2

[4]Electric Generating Stations Eddystone #3 and #4 and Chester #10 and #11

[5]Already adjusted for replacement factor for estuarine use

III. LOWER BASIN MODEL-RESERVOIR COMBINATION ANALYSIS

The Lower Basin Model is a condensed version of the Total Basin Model. Beginning with the flow at Montague as the headwaters, the study area extends down to Trenton, as seen in Figure I-1. It is here at Trenton that flow objectives are tested to find the maximum sustainable low flow objective for various reservoir combinations. Using the 17 different reservoir combinations described in Table I-1, the objectives are analyzed for nine historical events, ranging from the worst event in the past 50 years to an average event.

LOWER BASIN MODEL

Fixed Montague

By limiting the study area to begin with the flow at Montague, the back-up procedure used to operate the New York City reservoirs is eliminated from the Lower Basin Model. Primarily, this fixed Montague serves the purpose of maintaining constant New York City reservoir operations throughout the lower basin reservoir analysis.

The fixed Montague flow is determined from the Base Run with no lower basin reservoirs on line. The flow at Montague is then written on a separate tape to be used as input to the Lower Basin Model. Because the proposed diversions of the D&R Canal are based on the New York City reservoir storage, they are also written on this separate tape. This new tape is used along side the original incremental inflow tape to create the driving force of the Lower Basin Model.

From Table I-1, there are two different New York City reservoir input conditions: 1) Cannonsville existing storage at 95,7000 mg and 2) Cannonsville modified storage at 108,750 mg. This therefore requires two separate tapes to be generated as input into the Lower Basin Model, each being used for the appropriate reservoir combination.

Prompton Reservoir Scheme

All the reservoirs analyzed with the Lower Basin Model are located between Montague and Trenton, save one. The one important exception is Prompton. It is located in the upper basin, above Montague. Therefore, a fixed flow condition at Montague cannot accurately describe the upper basin when Prompton is on line. A fixed Montague would include the natural flow from Prompton, not as it is operated as a reservoir. For this case, another Montague scheme is used because the lower basin runs are designed to keep the New York City reservoirs' releases and diversions the same as the Base Run or the increased Cannonsville storage run.

In order to maintain a constant operation of the New York City reservoirs regardless of whether Prompton is on line, the following scheme is devised to allow the New York City reservoirs to receive "credit" for the natural inflow at Prompton and to allow Pennsylvania to use Prompton's additional releases to maintain Trenton's flow. Figure III-1 shows schematically this procedure. The previous total basin runs (with Cannonsville existing and modified) routed Prompton's natural inflow down to Montague with a real lag time of about 18 hours. This then fixes the New York City reservoir's operations. An estimate of the Montague flow without the Prompton natural inflow is made. This is done so the lower basin can operate Prompton as a reservoir and use its natural inflow as input to its storage. When necessary, releases can then be made to maintain the specified Trenton objective. This estimate took the actual flow at Montague and subtracted out the previous day's natural inflow to Prompton, a safe estimate of Prompton's contribution. Then the Lower Basin Model adds together this ficticious Montague flow and Prompton's reservoir operations with Prompton's releases (including spills, conservation and Trenton releases) lagged one day. This one day lag is done to be consistent with the subtraction of the

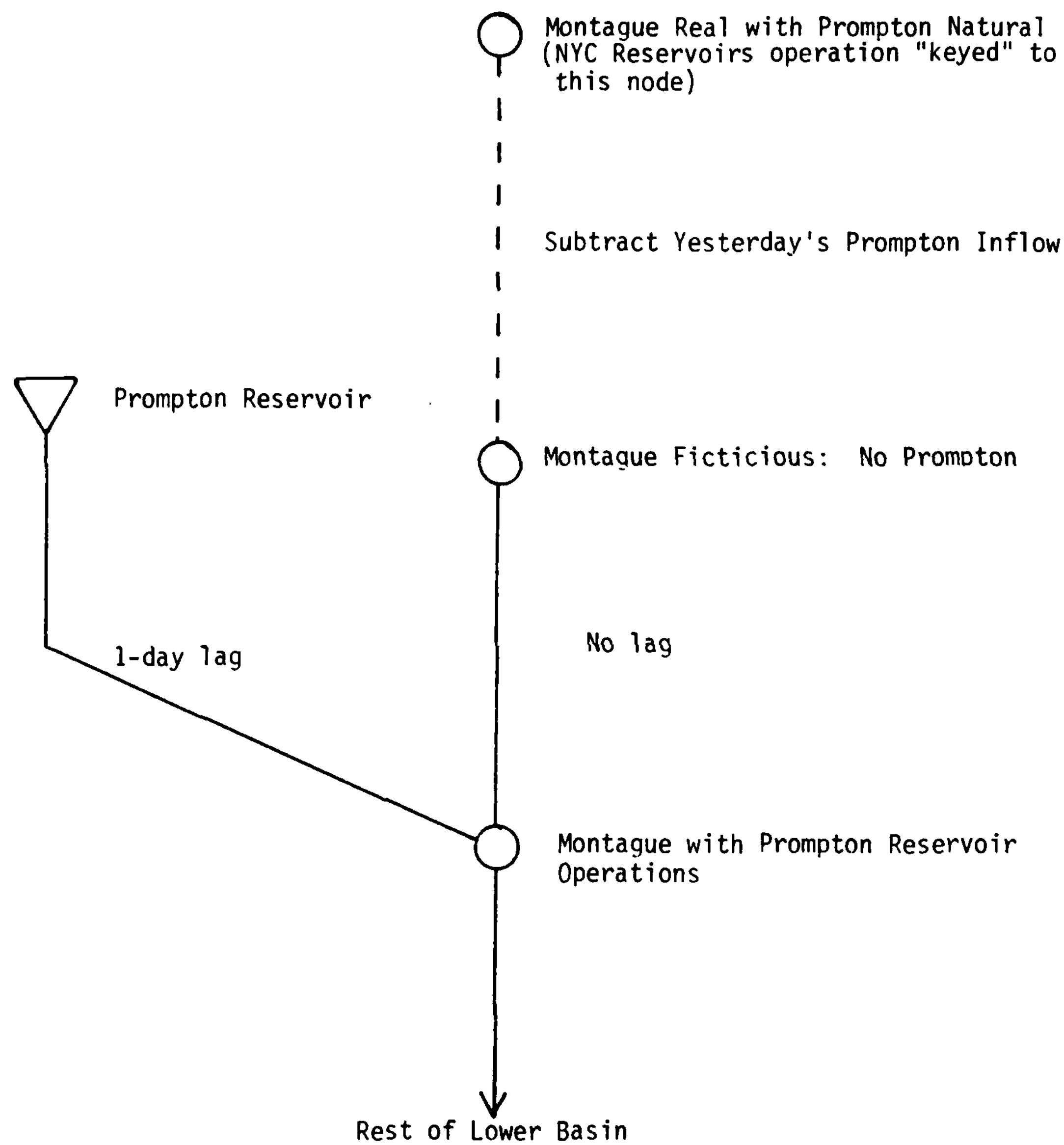


FIGURE III-1

Prompton Reservoir Schematic

previous day's natural Prompton inflow from the Montague flow. With this scheme, the New York City reservoirs' operations are constant throughout the entire reservoir analysis because they were operated on Montague's flows accounting for Prompton's natural flow before it was subtracted out.

Trenton Release Scheme

Unlike the Montague release scheme which backed the model up three days, recalibrates and reroutes the New York City releases, the Trenton scheme is far simpler. A next-day release is used such that yesterday's Trenton flow operates today's releases from the lower basin reservoirs. This will naturally lead to some "missed days". A missed day is one on which the Trenton flow is lower than the objective. With no alteration to this next day release scheme, a severe oscillation is set up due to the "miss one day - release next day" type of schedule. This is compounded by the fact that most of the releases are not seen until three days after the point of low flow. This three-day lag occurs because the routing time can be as much as two days from some of the reservoirs. This oscillation is more apparent as the objective goes higher, causing the actual monthly average flow at Trenton to be as much as 150 cfs lower than the target.

To overcome this missed target, a strategy is set up such that today's release is based on the release made three days ago by subtracting (that release of three days ago) from today's Trenton flow to better estimate the natural flow at Trenton. This strategy takes into consideration both the next day release scheme plus the two-day maximum route time. With this method, there will always be that first "missed day". However, any oscillation will be much less noticeable and monthly averaged missed targets are rare. When they do occur, they are on the order of 5-10 cfs lower than the target, an acceptable deficit.

Merrill Creek

The Merrill Creek reservoir is used specifically to replace the water to be used by the power plants within the Delaware River Basin (see Table II-4). That consumptive use is 126.9 cfs. This includes a 20.48 cfs power plant use below the Delaware Memorial Bridge. Merrill Creek is required to replace these consumptive uses when the Trenton flow is below 3000 cfs, releasing into the Delaware River just above Riegelsville. The water for its storage is skimmed at a maximum rate of 145 cfs from the Delaware River at Belvidere when the Trenton flow is greater than 3145 cfs. These release/skim targets are operated using the next day scheme as is the Trenton objective. Because of this and the fact that not all of the 126.9 cfs release will be seen immediately at Trenton due to routing, the release/skim targets are changed to 3100 and 3200 cfs respectively. In the simulation, Merrill Creek acts as a reservoir but is not operated to maintain the Trenton objective. It merely skims and releases, based on the previous day's flow at Trenton. Because Merrill Creek is not used to maintain any particular flow objective, its evaporation and conservation release are set equal to zero.

This release/skim scheme is not applicable when the target approaches and exceeds the 3100 cfs mark. Consider an objective of 3300 cfs: all the other reservoirs are releasing to maintain 3300 cfs while Merrill Creek is skimming to replenish its storage. Once Merrill Creek is full, it would never lose any volume through evaporation or conservation release nor would it release anything because Trenton's flow would always be above 3100 cfs. Merrill Creek would therefore quit skimming and would no longer be counteracting the other reservoirs' releases. However, the initial reason for including Merrill Creek to replace power plant uses would not be accomplished. For this reason, the release/skim scheme is altered when the objective exceeds 3100 cfs. For those targets, Merrill Creek would release at the target and skim at 100 cfs above the target. While this scheme does not use the full potential of Merrill Creek's storage capacity, it would at least contribute to the basins operations by making some releases rather than none at all.

Evaporation Calculations and Conservation Releases

Information received from the Philadelphia District Corps of Engineers allowed updating and improvement in the evaporation calculations. The New York City reservoirs' evaporation values are not changed so that the total basin runs of Phase II can be compared with the final regulated run of Phase I. The lower basin reservoirs use the new information. Table III-1 gives the values used for the lower basin reservoirs. Appendix M[1] assigns a percentage of the yearly lake evaporation for each reservoir to the months of May through September. The average monthly rainfall for each reservoir was taken from plate 8 of Appendix M. The net evaporation, as discussed fully in the Phase I report, is calculated as the evaporation minus one-half the precipitation on a monthly basis. Table III-2 gives the evaporation calculated for each of the lower basin reservoirs including Blue Marsh.

Also specified in Table III-2 are the conservation releases for each of the lower basin reservoirs. The conservation releases are set equal to the 7-day low flow which has a recurrence interval of 10 years. The Q7-10 flows are selected from the frequency analysis of the natural simulation performed in Phase I.

RESERVOIR COMBINATIONS ANALYSIS

The Lower Basin Model as described above is used to analyze the 17 combinations in Table I-2. The purpose is to define the maximum maintainable flow objective at Trenton for each of the reservoir combinations for selected low flow annual events.

The model defines a near-perfect operation of the reservoirs. It should be emphasized that the resultant maintainable flows are best used for the relative comparison of reservoir combinations. It is likely that the modeled flow objectives are higher than could actually be obtained by the physical operation of the existing and proposed reservoirs.

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[1] Report on the Comprehensive Survey of the Water Resources of the Delaware River Basin, Appendix M.

TABLE III-1

LAKE EVAPORATION FOR LOWER BASIN RESERVOIRS

Reservoir	Annual Lake Evaporation (inches)	Percent Occurring May - Sep
F.E. Walter	30.0	71
Prompton	30.0	71
Hackettstown	31.5	70
Nockamixon	33.5	68
Blue Marsh	33.5	68
Beltzville	29.0	66

Source: Report on the Comprehensive Survey of the Water Resources of the Delaware River Basin, Appendix M U.S. Army Engineer District, Philadelphia, April, 1960.

TABLE III-2

LOWER BASIN RESERVOIRS EVAPORATION AND CONSERVATION RELEASES

Reservoir	Net Evaporation (cfs-days)[1] Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Conservation Releases[2] (cfs)
Beltzville	0.01	0.18	-0.49	-0.61	2.30	2.96	2.16	2.63	2.53	3.08	-0.68	-0.44	35.0[3]
FE Walter	-0.87	-0.16	-1.72	-1.53	4.38	5.28	4.26	4.99	6.03	-1.23	-2.53	-1.23	57.0
Prompton	-0.30	-0.06	-0.60	-0.51	2.01	2.18	1.86	2.21	2.43	-0.50	-0.97	-0.50	6.5
Nockamixon	-0.43	0.61	-0.43	-0.45	4.93	5.10	4.05	4.64	5.60	0.26	-0.85	-0.45	11.0
Hackettstown	-0.46	-0.31	-1.21	-0.96	4.38	4.14	3.55	4.20	4.43	-0.37	-1.44	-0.74	12.2
Blue Marsh	-0.29	0.40	-0.29	-0.30	3.28	3.37	2.69	3.08	3.72	0.17	-0.57	-0.29	41.0[4]

[1]A positive value implies more evaporation occurred
A negative value implies more precipitation occurred

[2]Q7-10 value from the Naturalized Run in Phase I

[3]From Beltzville Regulation Manual, Q7-10 equals 20 cfs

[4]From Blue Marsh Regulation Manual, Q7-10 equals 39 cfs

Definition and Calculation of Events

Nine events are chosen to analyze the different reservoir combinations. These are the worst event, 2nd worst annual event, 3rd worst annual event, 4th, 5th, 10th, 15th, 20th and 25th worst annual events. The model simulation uses only these nine selected events, not a full 50-year simulation. Therefore, these events are isolated from the total 50 years of information. In order to choose these events, test runs are made on combinations One and Seventeen. Both of these combinations are run for two Trenton objectives, 2500 and 3200 cfs. An analysis of the drawdowns of the reservoirs during these four 50-year simulations is carried out to aid in the prediction of the worst events.

The definition of an event is the period of time between two full reservoir states, i.e., from full reservoir, drawdown, recovery, to full. The New York City Water Year, June 1 to May 31 is chosen as the period to describe annual events because the lower basin reservoirs fill up almost entirely every June or July. There is one exception: the drought from 1964-1966 is considered a single event because the reservoirs never achieve a full storage level during those two years.

The severity of each event is determined by the maximum drawdown of the reservoir system during the New York City Water Year. This drawdown is the absolute change in volume of the reservoir storage level. This definition will eliminate any possible overlapping of drought severity. The two targets are chosen to give a wide range of responses by the reservoirs. With only Beltzville on line (Combination One) the 3200 cfs objective produces many consecutive years of negative storage. An absolute difference is still calculated. The 2500 cfs objective produces far fewer negative years. For the case of all the reservoirs on line (Combination 17) and a 2500 cfs objective there are no negative years at all, however the absolute change in volume is still used to predict the worst events. The following is an example of only Beltzville trying to maintain a large target, resulting in consecutive years of negative storage.

A beginning point for an event could be negative storage, let us say -5 BG. If the storage then dropped to -20 BG, the severity is only -15 BG, not -20 BG. This method will also credit a year with recovery. For instance, reverse the example above. Begin at -20 BG and end at -5 BG. The "severity" is +15 BG, thus, not even accountable in the worst event list. Only drawdowns in the storage level are considered deficits.

The maximum drawdown is calculated on every year of each of the four runs described above. Then, each year within each run is ranked, with the highest deficit being the worst. These four rankings are combined to produce the final rankings, from which the nine events are chosen. Table III-3 gives the final results. As expected, 1964-1966 was the worst event in the 50 year history. The 25th worst annual event, June 1, 1935 to May 31, 1936 is an average year.

The nine events are then run back to back in the simulation. Because they are totally exclusive events, the reservoir storages are artificially set to their maximum storage on June 1, the beginning of each annual event. The worst event which covers the period from June 1, 1964 to May 31, 1966 is of course, allowed to run naturally past June 1, 1965. The 3rd, 4th, and 5th worst events have very similar inflow characteristics. Because of this, different reservoir combinations bring about a different order of worst events. This is the case for the events of 1931-32 and 1957-58. For the most part, 1957-58 is the third worst event and 1931-32 is the fourth. However, in the combinations where FE Walter or Nockamixon are not used as reservoirs (Combinations 1, 2, 4 and 5), 1931-32 is the third worst event. Therefore, for these four combinations, the final ranking in Table III-4 uses 1931-32 for the third worst event instead of 1957-58 that all the other combinations use. Examination of the Natural Flow Simulation of Phase I shows that the inflows to FE Walter and Nockamixon are much higher for 1931-32 than for 1957-58. This allows for more available storage to maintain a higher Trenton objective.

Procedure of the Reservoir Combination Analysis

The definition of the maximum sustainable flow objective is that objective which draws the reservoirs exactly to their zero usable storage level. Daily releases needed to maintain the Trenton flow are made

TABLE III-3

EVENT DEFINITION

June 1 - May 31

	EVENT	YEAR
Simulation Group 1	Worst	1964-66*
	2nd	1930-31
	3rd	1957-58
	4th	1931-32
	5th	1966-67
Simulation Group 2	10th	1962-63
	15th	1936-37
	20th	1968-69
	25th	1935-36

*Only 2-year event

entirely from the percent fullest reservoir on that particular day. In order to exactly predict the objective for a particular event, an indefinite number of objecitves would have to be tested. Therefore, the number of objectives is limited to a range which will produce positive and negative reservoir storages. From these objectives and storages, a zero storage level with corresponding objective is determined.

The nine events in Table III-3 are split into two groups for simulation purposes. The first group contains the first five events, the second group contains the last four events. Each group is then run separately, testing various objectives for different conditions. This is done because the objectives for the last four events would not be able to reliably predict a zero storage for the first five events and vice versa. The first five use a range of 300-400 cfs at increments of 100 cfs. Therefore, no more than four objectives are tested for the first five events. The last four events use a much wider range, generally on the order of 900-1200 cfs, at increments of 300-400 cfs. A maximum of three objectives test the last four events.

The methodology of estimating the flow objectives is done mathematically and graphically. Given two runs for one reservoir combination where one produces a positive storage due to an objective too small and the other a negative storage due to an objective too large for a particular event, the drawdown periods in days are estimated from a full storage level to the minimum storage level. In the case of the objective being too small, the remaining storage is divided by this number of days and an approximate increase in the target for each day is found. The same is done for the case of the negative storage: this case determines the decrease in the target for each day. These two estimates are averaged and become the mathematical average. To check this, the specified objective is plotted against the resulting storage, one negative and one positive, and the zero deficit point is found on the graph by connecting the two points. The mathematical average and the graphical zero point are used to determine the final low flow objective. Using both of these methods, the separate objective estimates are quite close, most times within 20 cfs. The final results are given in Table III-4.

TABLE III-4

TRENTON FLOW OBJECTIVES
(Flow in cfs)

Combination	Reservoirs	Event Worst	2nd	3rd	4th	5th	10th	15th	20th	25th
1	Beltzville, Cannonsville existing	2270	2370	2420	2430	2440	2760	3040	3220	3330
2	Beltzville, Cannonsville modified (m)	2280	2380	2430	2440	2450	2720	3030	3210	3350
3	Beltzville, Cannonsville (m), FE Walter (m)	2630	2710	2830	2840	2890	3190	3480	3780	4060
4	Beltzville, Cannonsville (m), Merrill Creek	2410	2510	2540	2550	2560	2810	3070	3260	3360
5	Beltzville, Cannonsville (m), Prompton (m)	2430	2540	2600	2610	2630	2940	3280	3450	3650
6	Beltzville, Cannonsville (m), Nockamixon	2400	2540	2560	2580	2670	2980	3250	3490	3730
7	Beltzville, Cannonsville (m), FE Walter (m), Merrill Creek	2760	2820	2910	2930	2980	3220	3510	3800	4100
8	Beltzville, Cannonsville (m), FE Walter (m), Prompton (m)	2770	2820	2970	2980	3030	3350	3640	3970	4300
9	Beltzville, Cannonsville (m), FE Walter (m), Nockamixon	2730	2850	2980	2990	3070	3390	3630	3940	4460
10	Beltzville, Cannonsville (m), Merrill Creek, Prompton (m)	2550	2640	2710	2730	2740	2980	3310	3490	3710
11	Beltzville, Cannonsville (m), Merrill Creek, Nockamixon	2500	2620	2630	2640	2740	2970	3220	3450	3750
12	Beltzville, Cannonsville (m), Prompton (m), Nockamixon	2580	2670	2770	2800	2830	3130	3460	3690	4100
13	Beltzville, Cannonsville (m), FE Walter (m), Merrill Creek, Prompton (m)	2870	2920	3020	3050	3080	3390	3680	3970	4360
14	Beltzville, Cannonsville (m), FE Walter (m), Merrill Creek, Nockamixon	2830	2930	3000	3060	3070	3380	3680	3970	4490
15	Beltzville, Cannonsville (m), FE Walter (m), Merrill Creek, Prompton (m), Nockamixon	2890	3000	3090	3150	3230	3500	3810	4170	4710
16	Beltzville, Cannonsville (m), FE Walter (m), Merrill Creek, Nockamixon, Hackettstown	2860	2950	3020	3090	3210	3480	3750	4150	4680
17	Beltzville, Cannonsville (m), FE Walter (m), Merrill Creek, Prompton (m), Nockamixon, Hackettstown	2970	3060	3170	3310	3380	3610	3920	4260	4840

NOTE: All combinations containing Prompton route its releases ar[illegible] Montague.

Results of the Reservoir Combination Analysis

The results show that as more reservoirs are put on line, the maximum sustainable low flow objective increases. As the events become less severe, the objective also increases. The lowest worst event target is 2270 cfs for Combination One, and the highest is 2970 cfs for Combination 17. For an average event (25th worst event) this range is from 3330 cfs (Combination One) to 4840 cfs (Combination 17). There are, however, anomalies to the general trend of an increased target with increased available storage.

Prompton has less storage available than does Nockamixon. This would lead one to surmise that a combination which replaces Prompton with Nockamixon would be able to sustain higher maximum flow objectives. The results show this is not the case in almost half of similar events. Combination 5 (with Prompton) and 6 (with Nockamixon) are good examples of the anomaly. The worst event has a higher objective using Prompton than Nockamixon, 2430 cfs and 2400 cfs, respectively.

The events oscillate, first having Prompton better for flow conditions, then Nockamixon. The years where Prompton consistently produces a higher objective are 1964-1966 (2-year worst event), 1931-1932 (3rd worst event) and 1936-1937 (15th worst event). On a closer look at the incremental inflows, on an average monthly basis Prompton indeed has much more flow than Nockamixon for these years in question. The combination pairs of 8 and 9, 10 and 11, 13 and 14 (with Prompton and with Nockamixon respectively), all show similar patterns as 5 and 6. The basin obviously reacts differently under stress conditions. For an average year (25th worst event), Prompton does not come close to maintaining the objective that Nockamixon can. This is just the case for Combinations 5 (with Prompton) and 6 (with Nockamixon) where they maintain an objective of 3650 and 3730 cfs respectively.

A second slight irregularity in Table III-4 is Combinations 1 and 2, Cannonsville existing and modified storage, respectively. With Cannonsville releasing to meet the Montague objective, there is very little difference in the maintainable Trenton objective, particularly in the first five events. The same is true for the last four events with only an exchange of ranks. Again, the difference is very slight and can be considered almost identical objectives.

IV. TOTAL BASIN MODELING

The purpose of the Lower Basin Model is to predict a flow objective for a particular reservoir combination for a given event as described in Chapter III. It is to do this calculation as efficiently as possible, looking at a very reduced study area. Once the maximum sustainable low flow objective has been determined for the worst event, the next step is to model and analyze the effects of using that objective with the Total Basin Model for various New York City reservoir operating schemes and different techniques used to credit Prompton's releases to Montague or Trenton. The statistical flow characteristics will also be analyzed for the Base Run, Combination One (Beltzville only) and Combination Seventeen (all reservoirs operating).

For the total basin modeling analysis of the Prompton and New York City reservoir operating schemes, a single reservoir Combination from the lower basin analysis has been chosen. This is Combination Eight in Table I-2 which includes Beltzville, Cannonsville modified, FE Walter and Prompton Reservoirs. This combination is suitable for examining the effects of Prompton's different crediting schemes and for the analysis of the special set of New York City operating rules. The Trenton flow objective is the result of the reservoir analysis in Chapter III. It is the worst event's maximum sustainable flow for the specified reservoir combination of 2770 cfs. This will be held constant for this portion of the Total Basin Modeling.

Because the study area with the Total Basin Model encompasses the basin down to the Delaware Memorial Bridge, another basin operation is included. Blue Marsh Reservoir is located in the Schuylkill River Basin.

The Schuylkill River makes its confluence with the Delaware River between Trenton and the Delaware Memorial Bridge. Blue Marsh does not release to maintain any specific flow objective. It is however, modeled as a reservoir with a conservation release, evaporation factors and supports a water supply withdrawal for the Schuylkill River basin. This reservoir operation is essential to proper modeling of the basin around the area of Tulpehocken Creek and Schuylkill River. Blue Marsh has a conservation release of 41 cfs and a water supply withdrawal of 9 cfs. In the summer months between May 1 and September 30, Blue Marsh is used as a recreational area. For this reason, its maximum storage is raised to 22,900 acre-feet from 17,600 acre-feet which it maintains for the rest of the year.

PROMPTON RESERVOIR

Prompton Reservoir is located in the upper basin above Montague. Its releases are naturally routed to Montague via the Lackawaxen River. Because it is releasing to maintain a Trenton flow objective and at the same time must pass by Montague, its releases could help augment either flow objective. Two different techniques of crediting Prompton's augmentation are analyzed. The first is identical to the Lower Basin Model in that the New York City reservoirs are not allowed to change their releases from the base run. This run is referred to as Prompton *Around* Montague. Prompton's releases are not used to augment Montague's flow.

The second run does just the opposite: Prompton's releases, even though they are determined according to the Trenton flow objective, are used to augment Montague's flow to help meet its objective. This is called Prompton *Through* Montague and results in the New York City reservoirs operating differently.

Prompton *Around* Montague

In this case, Prompton's reservoir releases are modeled to maintain the flow objective at Trenton without crediting the releases to Montague's

flow. The releases are actually routed to Montague. A special technique is used to adjust the Montague objective to take into account the additional flow created by Prompton's releases and to keep the operations of the New York City reservoirs identical to the Base Run made with Cannonsville modified storage. This is accomplished in the Total Basin Model by using a simple mass balance to raise or lower the Montague objective:

Change in Objective = (Prompton Q710 Conservation Releases + Prompton Spills + Prompton Trenton Releases) - Prompton Natural Inflow

Montague Objective = Original Objective + Change in Objective.

The change in objective is positive (raising the Montague objective) when Prompton reservoir releases are more than its natural inflow. This occurs when Trenton is in a low flow condition. The additional Prompton releases naturally raise the Montague flow. If the objective were not raised also, the New York City reservoirs would release less than in the base run. The change in objective is negative (reducing the Montague objective) when the natural inflow is greater than a release. This occurs usually when Prompton is recovering from a drawdown period, thus holding back most of the natural inflow. The decrease in natural inflow from Prompton produces a lower flow at Montague which would cause the New York City reservoirs to release more if the objective were not also reduced.

Exhibits IV-1 through IV-4 give samples of the output for Prompton Around Montague. Exhibits IV-1 and IV-2 are the actual monthly average flows at Montague and Trenton respectively. Exhibits IV-3 and IV-4 are the average monthly total storages for the New York City reservoirs and the lower basin reservoirs, respectively. These four basin results are compared to the Prompton Through Montague simulation and are discussed in the following paragraphs.

Prompton *Through* Montague

For this case, Prompton's releases are governed by the Trenton objective, yet allowed to help augment the Montague flow. Therefore, no changes are made in the Montague objective. Using the same Trenton objective of 2770 cfs as Prompton *Around* Montague, the results are shown in Exhibits IV-5 through IV-8. Exhibits IV-5 and IV-6 are the monthly average flows at Montague and Trenton respectively. Exhibits IV-7 and IV-8 are the average monthly total storages for the New York City reservoirs and the lower basin reservoirs, respectively.

Prompton's releases which in this case are now credited to the Montague flow reduce the required releases from the New York City reservoirs. Exhibit IV-7, which is the total New York City reservoir storage shows a surplus of 12.1 bg through the 60's drought. Exhibit IV-3, total New York City reservoir storage for the Prompton *Around* Montague case, shows a deficit of 6.2 bg through the 60's drought. Therefore, a net gain of 18.3 bg is seen by the New York City reservoirs, when Prompton's releases help augment Montague's flow.

In the case of Prompton *Through* Montague, the flows at Montague seen in Exhibit IV-5 will be less than the other case of Prompton *Around* Montague given in Exhibit IV-1. With Prompton credited to the Montague flow, the objective never changes and therefore will result in lower average flows. The periods to examine are August - November of 1964 and June - September of 1965. Prompton *Around* Montague produces an average flow for each period of 1760 cfs and 1660 cfs respectively. Prompton *Through* Montague produces 1660 and 1550 cfs for each respectively, 100 cfs lower than Prompton *Around* Montague.

This reduction of the Montague flow makes less water available to the lower basin. With the Trenton objective constant for the two cases, the lower basin reservoirs must therefore release more to maintain the same Trenton objective. The flows at Trenton for each case are nearly the same. The Trenton flows for those same periods average 2790 cfs and 2810 cfs respectively for the Prompton *Around* Montague case as seen in Exhibit IV-2 and 2810 cfs and 2830 cfs for Prompton *Through* Montague given in Exhibit IV-6.

The storage of the lower basin reservoirs also reflect the additional releases required to maintain the Trenton objective. During the 60's drought, when Prompton's releases are credited to Montague in the Prompton *Through* Montague case, five consecutive months of negative storage occur in the lower basin reservoirs as seen in Exhibit IV-8 with a maximum deficit of 13.7 bg. When Prompton's releases are not credited to Montague in the Prompton *Around* Montague case, the total lower basin reservoir storage show a slight surplus of 4.1 bg as seen in Exhibit IV-4. The total loss bv the lower basin reservoirs is 17.8 bg, almost exactly equal to the gain by the New York City reservoirs.

In conclusion, when Prompton's releases are credited to the Montague flow, the New York City reservoirs benefit by making less releases while the Montague flow is reduced in magnitude and the lower basin reservoirs release much more water thus reducing their available storage.

NEW YORK CITY RESERVOIR OPERATIONS

For the Prompton *Through* Montague case described above, the increase in the New York City reservoir storages would permit greater diversions. A new set of New York City operating rules specified by the New York State Department of Environmental Conservation are analyzed. In this section, the results from Prompton *Through* Montague are compared to the results from the special operating rules.

Table IV-1 gives both the special operating rules and those used in the rest of the reservoir analysis, referred to here as the *Original* operating rules. The Normal System Condition remains the same. The *Special* Drought Warning Condition reduces the Montague objective by 100 cfs and raises the diversions by 50 mgd. The *Special* Drought Condition raises the diversions by 120 mgd and keeps the Montague objective the same. Both of these cases use the same flow objective at Trenton of 2770 cfs and use the Prompton releases to credit Montague's flow. Exhibits IV-9 through IV-12 of the *Special* rules are compared with Exhibits IV-5 through IV-8 of the Prompton *Through* Montague case. Exhibits IV-9 and IV-10 are the average monthly flows at Montague and Trenton respectively. Exhibits IV-11 and IV-12 are the average total storage of the New York City reservoirs and the lower basin reservoirs, respectively.

TABLE IV-1

NEW AND EXISTING NEW YORK CITY RESERVOIR OPERATING RULES

Operation		CONDITION Normal	Drought Warning	Drought
Montague Objective (cfs)	*Special**	1750	1650	1525
	Original	1750	1750	1525
New York City Diversions (mgd)	*Special**	800	650	550
	Original	800	600	430

*Specified by New York State Department of Environmental Conservation

The most striking comparison is the total New York storage available during the 60's drought shown in Exhibit IV-11 for the *Special* rules and in Exhibit IV-7 for the *Original* rules. The *Original* rules never create a deficit throughout the 60's and actually end up with a surplus of 12.1 bg. The *Special* rules drawdown the reservoirs such that six months of consecutive deficits occur from September 1965 to February 1966 with a maximum monthly average deficit of -34.5 bg. Seven months later in October 1966 (water year 1967), a four-month deficit begins with a maximum monthly average deficit of -26.2 bg.

Because both of these cases use the Prompton *Through* Montague condition for crediting the Prompton releases, there is not too much difference in the average monthly flows at Montague. Comparing Exhibit IV-9 from the *Special* rules and Exhibit IV-5 from the *Original* rules, the only differences occur when one considers that the Drought Warning Montague objective is reduced from 1750 cfs to 1650 cfs in the *Special* rules. This does, however, affect the operations of the lower basin reservoirs. With a

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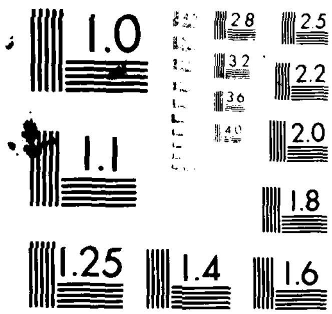

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

reduction of 100 cfs in the Montague flow, less water is routed down to Trenton. Thus, the lower basin reservoirs must release more to maintain the same Trenton objective as before. This is only compounded by the treatment of Prompton's releases, allowing them to help augment the Montague flow and therefore are not directly augmenting the Trenton flow. Exhibit IV-8 gives the total storage for the lower basin reservoirs for the *Original* rules. Exhibit IV-12 shows the same for the *Special* rules. During the 30's drought, the number of consecutive average monthly negative storages increases with the *Special* rules as well as the severity from -4.0 bg to -7.4 bg. The 60's drought produces similar results. The maximum deficit increases from -13.7 bg using the Base Run rules to -18.1 bg using the *Special* rules and extends the consecutive negative months by one. The change in the New York City reservoir operating rules do not have as strong an effect on the lower basin reservoirs as for the New York City reservoirs. Nonetheless, any operating rule change for the upper basin will for this case draw down the lower basin reservoirs even further by requiring increased releases.

The increased releases from the lower basin reservoirs maintain approximately the same Trenton flow with either operating rules. This is shown in Exhibit IV-10 which gives the average monthly flow at Trenton for the *Special* rules and Exhibit IV-6 gives the results from the *Original* rules.

LAKE WALLENPAUPACK

Lake Wallenpaupack has been regulated by a power plant since 1925. Its regulated releases have been designated as natural observed outflow at that node and used as such in all analyses in both Phase I and II. However, because of its regulation, it is conceivable that Lake Wallenpaupack could have supplemented the flow at Montague during the 60's drought even more than the historical contribution already made. With this in mind, a release scheme for this study only was devised in coordination with the Pennsylvania Department of Environmental Resources such that maximum releases are made without considering optimal generation of hydroelectric power. Any releases from Wallenpaupack will help augment Montague's flow to meet the 1750 cfs

objective, thus reducing the releases from the New York City reservoirs. This section compares the results of using these special Wallenpaupack releases to the results of using the historical outflows for two reservoir combinations, 2 (Beltzville and Cannonsville modified) and 17 (all reservoirs on line).

The scheme in use begins in June 1962 when the New York City reservoirs first fall into Drought Warning Condition and ends in May 1967 when the New York City reservoirs are again in the Normal Condition. Lake Wallenpaupack's maximum releases for each day of the month are determined from a minimum elevation schedule. Lake Wallenpaupack is normally full at elevation 1187 feet (not including extra flood storage capacity). The minimum elevation of the reservoir is 1165 feet. A strict schedule is set up from June 1 to December 1 of minimum allowable elevations as given in Table IV-2. The releases will drawdown Lake Wallenpaupack in order to arrive at these storage elevations.

TABLE IV-2

MINIMUM ELEVATIONS OF LAKE WALLENPAUPACK

June 1	1187 feet
July 1	1184 feet
August 1	1180 feet
September 1	1177 feet
October 1	1172.5 feet
November 1	1168 feet
December 1	1165 feet

The maximum releases for each month are determined by first calculating net inflows to the reservoir from actual monthly changes in storage, and actual monthly releases. Natural inflows to Lake Wallenpaupack are not available as such and cannot be determined from a correlation and extension procedure; the USGS station at Wallenpaupack has always recorded regulated releases from the water power reservoir. From the elevation schedule, the change in storage is calculated. Accounting for the net inflow, the maximum release possible is determined. For example, the June releases will draw down the storage elevation by three feet to obtain a July 1 elevation of 1184 feet. Adding the inflow to this amount, the maximum releases for each day are calculated. The releases, being a function of variable inflow change from month to month, and each month from year to year. For example, although the month of June releases are set as high as possible as are all the months, each June will not release the same amount.

From December 1 to June 1, Lake Wallenpaupack refills using the calculated net inflows such that the maximum possible storage is available on June 1. This means that although a conservation release of 70 cfs will try to be maintained, it is not always possible to release 70 cfs in order to have a full reservoir on June 1.

The results of the two combinations show that Lake Wallenpaupack is indeed helpful in maintaining the Montague objective. Fewer releases are made by the New York City reservoirs thus allowing more water to be available to raise the minimum storage remaining in the New York City reservoirs at the critical low point of the simulation. Both Combinations 2 and 17, when comparing the special releases versus historical releases from Lake Wallenpaupack result in an increased remaining storage capacity of 19 bg for the New York City reservoirs when the special releases are made. The lower basin reservoirs which are still operating to maintain a set Trenton objective, are hardly affected. Slight increases in Montague's flow require less releases to be made from the lower basin reservoirs, producing an increase in the remaining total storage of the lower basin reservoirs of approximately 1 bg for each combination.

CCPM WATER RESOURCES DIVISION
PROGRAM AROUND MONTAGUE

• • • • P H A S E II • • • •

DELAWARE RIVER DAILY FLOW MODEL
DELAWARE RIVER AT MONTAGUE 01438500

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	13496.6	17391.6	16667.6	5106.2	7150.1	6742.2	14254.9	11675.1	12645.9	10718.4	5827.8	3853.8
1929	2 16.-	1751.8	2297.6	2954.7	3241.6	12193.0	18673.6	9867.9	2766.4	2015.2	1849.7	1778.2
1930	2956.7	4582.2	5908.6	5493.6	5447.5	8057.3	5455.9	2945.0	4003.8	2243.6	2032.9	1966.5
1931	1897.6	1875.1	1508.6	1534.0	1941.9	6881.6	9542.6	8028.1	4446.0	6042.1	2232.2	1822.8
1932	1378.4	1926.5	2914.8	6766.2	6204.6	4288.9	11306.7	4863.0	4397.0	2747.6	2020.4	1996.5
1933	4916.[illegible]	9834.5	3152.9	4818.3	3713.3	8285.5	12437.2	3684.6	2442.9	1911.4	7165.2	7235.3
1934	3455.5	3714.2	4210.0	6150.3	2655.7	5940.6	11330.1	3755.1	2321.0	2893.2	2243.6	5166.2
1935	4151.6	5002.8	7191.1	6423.0	3172.5	11161.5	7912.7	6619.9	2926.6	5534.4	2511.9	1934.2
1936	2351.4	8692.0	4724.8	3814.8	2489.7	28695.8	13389.6	3504.6	3132.3	2143.1	2160.5	1881.6
1937	2100.4	3785.6	5244.1	9427.5	7660.0	4669.6	12615.6	7675.1	5250.0	3389.4	3007.2	2693.1
1938	4432.9	4525.1	5322.5	5713.0	8627.8	7379.7	7741.7	4013.6	4103.4	6199.6	6947.0	10376.2
1939	3271.2	4454.0	11310.7	3696.8	9474.6	12870.5	15043.3	3996.7	2302.3	1941.2	1999.7	1854.0
1940	2539.8	3397.8	2902.5	1764.5	1624.9	6335.8	22583.5	6718.9	4766.4	2881.6	2172.4	3523.8
1941	2361.6	5377.7	6621.[illegible]	45[illegible].1	4486.2	4567.1	9365.9	2456.9	2374.8	2077.0	2381.1	1813.3
1942	1855.4	1675.6	3158.5	2716.5	2407.3	8991.1	5755.9	7656.8	5633.5	2605.8	3063.0	5407.6
1943	7264.6	7435.7	8541.	6437.6	6305.4	12794.4	9233.6	14833.6	5636.9	2147.0	1847.2	1757.9
1944	2519.0	5771.9	2474.	1677.5	2176.3	6924.3	9734.3	3965.2	2416.4	1750.4	1746.3	1945.0
1945	1792.[illegible]	2017.7	3367.	4729.3	3273.1	17416.3	7208.3	8767.7	6752.1	9857.2	5916.5	4974.6
1946	5.73.	5371.4	5132.	7667.7	3357.2	11965.2	3293.3	9923.6	7026.2	2724.1	2463.7	2166.7
1947	2213.7	1955.6	1442.	4588.6	4851.5	7378.9	10977.2	13653.9	4963.5	6743.1	4632.1	2220.6
1948	17[illegible].	5349.3	7021.	2436.4	4962.6	1486[illegible].8	12501.5	8982.4	4991.3	3036.7	2375.1	1803.1
1949	1666.7	2914.4	5762.	11349.7	7366.5	5370.3	6520.4	6829.8	2555.9	1804.0	1813.5	1792.9
1950	1791.4	217[illegible].5	5232.	6362.3	4017.6	9319.0	11343.1	6629.5	5075.9	3457.3	2751.5	2197.1
1951	1779.7	5911.2	9712.	8543.6	12746.7	12722.0	13904.6	3270.1	3142.3	2937.4	2242.3	1832.1
1952	2564.5	8237.3	6631.	9213.0	7968.9	11130.3	16400.0	9641.2	5575.3	5753.6	2256.5	2744.8
1953	1602.3	4446.3	9755.	7860.4	7750.6	11011.5	12761.1	10125.1	3020.6	1960.7	1773.2	1774.7
1954	1911.7	2373.4	6625.	3195.2	6531.4	6904.1	6432.0	7704.5	2449.9	1799.0	1827.9	1617.5
1955	1755.4	6761.5	6261.	4250.2	3563.6	9524.0	6145.3	2758.2	2313.7	1819.1	13501.8	3171.8
1956	14 98.1	9303.3	3540.	3285.9	4659.5	8644.7	21509.0	8121.6	4365.2	2045.0	1753.6	1973.7
1957	1703.4	2751.5	6149.	4348.4	3808.2	5558.0	9362.5	3249.6	2099.8	1799.9	1906.5	1866.5
1958	1558.5	1756.0	7605.	5033.6	3469.9	6955.4	18504.5	8262.3	2271.3	2138.9	1797.5	2035.0
1959	3505.7	5244.2	3558.	4904.3	4437.3	6477.0	10276.5	3551.7	1898.3	1562.6	1797.1	1816.9
1960	4254.9	7159.2	7092.	5692.5	7361.8	3976.4	18439.2	4514.6	5560.0	3018.3	3745.0	7763.4
1961	3323.4	2562.6	2413.	1877.3	6917.4	9421.8	15095.0	7394.7	3270.3	1921.3	2214.6	1901.2
1962	1756.7	2144.4	2310.	5422.4	2413.3	7163.0	11083.6	2670.8	1772.4	1813.6	1766.1	1825.2
1963	1513.8	3710.1	2573.	2946.9	2755.1	5914.8	6955.8	3537.9	2039.3	1939.6	2008.4	1839.6
1964	1551.0	2153.	3664.	5738.7	3368.2	11760.6	7328.5	4038.1	2080.9	1773.5	1828.8	1860.9
1965	1[illegible]5.3	166[illegible].1	2[illegible]1.	2218.7	4[illegible]38.0	3771.3	5460.9	2211.0	1601.7	1699.4	1665.3	1671.4
1966	1655.[illegible]	1734.3	2512.	2327.7	3142.7	5048.8	3687.7	5633.1	3156.3	1629.9	1610.2	1607.3
1967	1553.0	2[illegible]1.	715[illegible].	4271.3	3577.9	6677.3	10406.0	6623.5	3448.4	2795.6	3316.9	1938.0
1968	[illegible]457.1	4603.6	[illegible]6.	2546.7	3553.3	75[illegible]6.4	4846.7	7373.7	7601.4	2998.2	1884.1	2060.4
1969	1444.7	4959.1	[illegible]	4[illegible]4[illegible].1	33[illegible]9.7	5819.6	9[illegible]45.4	4156.5	4156.8	4675.7	5414.8	1838.6
1970	1704.	47[illegible]	[illegible]	[illegible]1.1	73[illegible].8	[illegible]6.4	15[illegible]59.7	5494.3	2263.0	2021.2	1636.7	2073.5
1971	[illegible]54.3	4547.	[illegible]4.	3517.1	[illegible]	55[illegible]8.9	11147.5	6901.3	2174.9	1797.0	3257.1	2321.6
1972	[illegible]473.[illegible]	[illegible]	[illegible]745.	5710.9	[illegible]	11003.	14518.5	9362.5	14148.9	6698.6	2329.7	1734.1
1973	1776.7	1115[illegible]	[illegible]24.	[illegible]	5[illegible]47.1	7364.6	12[illegible]54.4	11917.5	11032.3	7060.6	4137.1	1975.7
1974	[illegible]	[illegible]	14169.	6278.6	7[illegible].5	[illegible]14.[illegible]	12276.9	6591.4	3332.2	2631.1	2572.2	4840.3
1975	3364.[illegible]	4[illegible]	[illegible]44.	8[illegible]4.1	1[illegible]75[illegible].8	12804.5	8566.9	8157.7	6204.9	3107.2	2342.8	4582.1
1976	659[illegible].4	67[illegible]1.5	454[illegible].	9151.8	14551.[illegible]	9474.1	7[illegible]64.6	6101.3	3325.7	3970.1	4085.0	2060.0
1977	4[illegible].1	[illegible]44.5	[illegible]5.	2442.6	4[illegible]9.7	15755.7	10149.4	4908.6	1956.3	1888.2	1868.1	6221.0
AVG	2[illegible]7.[illegible]	4744.4	5018.	5[illegible]5[illegible]	5275.4	9199.[illegible]	11[illegible]0.7	6510.2	4202.2	3292.0	2952.6	2827.1

EXHIBIT IV-1

[illegible] WATER RESOURCES DIVISION
PROGRAM [illegible] TABLE

• • • • • P H A S E II • • • • •

DELAWARE RIVER DAILY FLOW MODEL
DELAWARE RIVER AT TRENTON 01463500

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	[illegible]	[illegible]	27297.	[illegible]	[illegible]	12019.5	23208.6	17924.9	19112.0	24227.0	12020.4	8801.1
1929	[illegible]	[illegible]	[illegible]	[illegible]	7936.8	22134.6	27702.5	16857.4	5471.7	3395.2	3226.9	3576.2
1930	[illegible]	[illegible]	[illegible]	[illegible]	10774.5	15743.9	12351.3	6552.9	7634.2	3956.8	2859.6	2782.0
1931	[illegible]	[illegible]	[illegible]	[illegible]	4660.9	10525.4	14643.5	12454.7	7896.0	9233.9	3642.9	2900.0
1932	[illegible]	[illegible]	[illegible]	9424.2	5566.5	8567.3	18365.6	8314.9	6157.4	3773.9	2746.5	2751.1
1933	7351.2	[illegible]	7651.	8865.7	5775.1	18174.7	25613.2	9744.6	5113.3	3910.3	16588.3	19702.9
1934	7176.4	[illegible]	6619.	[illegible]	4967.1	12657.0	22116.9	10202.1	5875.4	4348.3	3455.4	9681.3
1935	[illegible]	[illegible]	[illegible]	11416.2	8527.6	18670.9	12693.7	9761.4	4896.9	15550.5	4719.4	4596.5
1936	[illegible]	17997.6	11915.	[illegible]	6761.9	56487.6	25218.7	7647.4	6675.1	3692.7	3351.9	2956.6
1937	[illegible]	4738.3	11061.	[illegible]	15909.6	10556.9	21260.8	14210.6	8119.3	5646.2	6610.8	4431.6
1938	[illegible]	[illegible]	[illegible]	12896.5	15729.1	13592.6	14187.0	7684.4	8856.1	16119.6	11647.2	16930.6
1939	7453.7	[illegible]	23639.	[illegible]	22126.4	23793.3	26178.3	7689.9	4066.8	3080.8	3016.3	2713.7
1940	[illegible]	[illegible]	4204.	[illegible]	4218.6	16075.6	43106.9	13793.6	10747.0	5160.9	3513.8	8521.2
1941	[illegible]	[illegible]	10431.	[illegible]	6634.1	15699.4	17696.3	4547.8	4782.3	4973.2	3908.0	2791.7
1942	[illegible]	[illegible]	[illegible]	[illegible]	8167.5	16562.6	11784.9	16630.4	10707.2	5651.4	13071.3	10305.8
1943	[illegible]	[illegible]	[illegible]	[illegible]	15624.8	22283.7	14837.6	23029.1	11413.4	4549.5	3126.6	2752.6
1944	[illegible]	[illegible]	4429.	[illegible]	[illegible]	[illegible]	19956.5	9172.2	6275.6	3504.9	2834.9	3405.3
1945	[illegible]	4114.1	[illegible]	[illegible]	5112.1	[illegible]	13875.6	16725.8	12764.6	23787.0	13133.6	11086.7
1946	[illegible]	[illegible]	17967.	[illegible]	[illegible]	[illegible]	7650.4	18105.3	16535.6	7272.9	5180.9	4132.4
1947	[illegible]	[illegible]	[illegible]	[illegible]	10096.8	16179.2	20869.1	28523.0	12890.2	18203.6	8410.5	4571.1
1948	[illegible]	12777.8	[illegible]	5413.	5562.3	28262.2	[illegible]	20424.4	11477.0	6884.7	5520.8	3355.6
1949	[illegible]	[illegible]	7214.	26539.1	16401.7	11355.4	14250.0	14456.3	5144.3	3894.5	3166.1	3054.1
1950	[illegible]	[illegible]	8546.	[illegible]	11485.5	18915.7	16621.7	11815.9	10134.0	6939.7	4258.4	3761.2
1951	[illegible]	21957.	21535.	16749.2	[illegible]	[illegible]	28132.3	7458.3	7497.5	7322.4	6073.4	3874.4
1952	[illegible]	[illegible]	15836.	[illegible]	17371.6	22738.7	34723.2	21190.6	12554.4	11235.3	6164.0	9456.6
1953	[illegible]	12296.9	22712.	19247.5	[illegible]	[illegible]	25371.5	18534.6	6775.3	3828.7	3069.7	3025.1
1954	[illegible]	4614.6	14973.	6242.4	11326.6	14946.1	11666.4	14491.7	4447.9	2800.1	2865.0	3454.8
1955	2873.7	[illegible]	11754.	9297.7	7959.6	16615.9	11640.5	5761.4	4396.6	2809.5	29217.5	6905.7
1956	[illegible]	[illegible]	[illegible]	[illegible]	12069.3	17762.9	31697.6	16785.8	9055.0	7821.5	3902.4	4775.0
1957	[illegible]	7474.1	14657.	8592.6	9302.7	12036.8	23549.5	7234.4	4014.8	2861.9	2735.1	2796.2
1958	2667.5	[illegible]	17475.	[illegible]	9622.9	19968.9	35312.3	19270.3	5444.6	4323.4	3401.4	3742.1
1959	7575.3	[illegible]	[illegible]	[illegible]	10039.3	13508.4	18497.0	7716.7	4319.3	3630.6	3800.2	4066.3
1960	7233.4	11567.3	17133.	[illegible]	16677.2	8194.2	33147.8	10552.0	9938.2	5918.4	7338.7	17751.8
1961	[illegible]	[illegible]	[illegible]	[illegible]	14379.2	22858.6	26493.9	15049.2	6579.3	4858.5	5174.7	3806.5
1962	[illegible]	[illegible]	[illegible]	11734.6	[illegible]	17778.1	[illegible]	5577.7	3232.9	2795.6	3100.2	2941.1
1963	[illegible]	[illegible]	[illegible]	5943.2	5527.6	21609.6	12190.5	7307.9	3872.2	3029.5	2915.6	2847.9
1964	2741.5	[illegible]	6151.	[illegible]	[illegible]	[illegible]	16217.9	9912.4	4234.8	3010.0	2757.7	2766.5
1965	2775.1	[illegible]	[illegible]	[illegible]	[illegible]	8283.0	9370.7	4942.7	2887.0	2745.2	2788.2	2822.0
1966	[illegible]	[illegible]	4745.	[illegible]	[illegible]	16834.1	7593.4	10551.2	5313.3	2849.1	2720.0	2942.3
1967	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6211.3	5602.5	10342.5	4495.5
1968	[illegible]	[illegible]	14071.	[illegible]	[illegible]	[illegible]	[illegible]	13841.2	18777.7	6475.8	3264.5	3612.3
1969	[illegible]	[illegible]	11127.	[illegible]	[illegible]	[illegible]	17021.7	[illegible]	8315.5	10969.0	16240.7	4533.9
1970	[illegible]	[illegible]	[illegible]	[illegible]	18551.6	11417.6	33666.2	11357.8	5396.2	4152.2	3756.0	3167.5
1971	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19637.4	[illegible]	7151.9	3556.7	8551.3	9176.9
1972	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22691.8	[illegible]	33861.1	14510.7	4516.0	3222.5
1973	[illegible]	[illegible]	24936.	[illegible]	[illegible]	15510.5	26395.8	23108.6	18107.7	16484.6	9298.6	5201.6
1974	[illegible]	[illegible]	[illegible]	[illegible]	15695.1	19106.9	25731.9	14006.6	7582.3	4602.2	5637.8	11655.0
1975	[illegible]	[illegible]	16794.	[illegible]	[illegible]	22276.2	17503.6	16203.9	14056.3	14026.1	6432.9	11576.4
1976	[illegible]	[illegible]	[illegible]	[illegible]	25484.2	16019.5	[illegible]	11443.2	7534.0	7914.2	7497.1	4395.0
1977	[illegible]	[illegible]	7239.	[illegible]	[illegible]	[illegible]	[illegible]	10015.6	4289.5	3448.3	3264.7	8252.5
AVG	6235.6	[illegible]	11532.	[illegible]	11615.3	[illegible]	20516.5	12870.0	8572.2	7073.0	6137.2	5740.7

EXHIBIT IV-2

[illegible] WATER RESOURCES DIVISION
[illegible]

* * * * * P H A S E II * * * * *

DELAWARE RIVER DAILY FLOW MODEL
COMBINED NYC RESERVOIR STORAGE (BG)

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	283.7	257.6	283.	282.9	281.7	282.5	283.6	283.5	283.4	283.0	281.6	273.9
1929	254.1	226.4	213.	214.4	199.1	232.6	282.3	283.5	275.0	254.6	222.0	188.7
1930	173.5	164.6	173.7	197.5	158.7	233.9	258.0	254.3	247.6	229.7	197.6	167.4
1931	132.7	76.5	61.7	67.2	51.7	54.6	127.4	176.6	194.4	196.8	197.4	176.6
1932	136.	[illegible]	[illegible]	125.6	166.5	168.8	226.7	250.3	242.7	234.4	206.9	172.9
1933	167.4	154.3	279.	274.3	231.9	219.6	264.6	281.3	265.1	234.1	208.9	243.1
1934	246.7	243.2	244.	255.5	254.2	258.6	281.4	281.7	264.5	237.0	212.4	196.2
1935	272.5	234.6	235.	214.5	250.4	271.5	283.5	282.5	266.8	258.6	246.1	216.0
1936	187.5	170.3	235.1	239.7	233.1	259.3	263.6	279.2	260.3	231.8	196.8	171.5
1937	142.5	151.2	156.	164.4	219.7	232.1	262.0	283.2	280.4	275.9	255.2	247.7
1938	240.1	259.3	265.	273.6	283.4	273.1	283.4	280.1	276.5	272.3	281.3	274.4
1939	277.6	273.[illegible]	262.7	279.1	276.2	283.5	283.7	278.4	257.2	226.3	191.9	156.0
1940	131.9	132.7	130.	123.1	108.0	176.5	223.1	282.6	278.5	262.3	233.6	213.2
1941	191.7	[illegible]	165.	221.2	213.9	211.3	246.0	256.8	235.7	207.3	186.7	144.2
1942	[illegible]	75.2	63.	83.3	69.6	117.4	173.4	193.1	215.1	198.6	174.3	150.7
1943	154.9	164.3	190.7	225.6	221.5	271.4	283.4	283.7	280.6	259.3	226.8	192.4
1944	152.7	[illegible]	161.	141.2	137.6	137.5	188.3	216.1	264.5	178.4	143.7	113.0
1945	91.5	74.2	64.	117.7	166.4	163.5	250.5	273.6	283.0	278.7	276.3	263.7
1946	276.6	277.5	262.	272.1	274.6	261.7	280.3	277.8	281.6	267.1	244.2	216.2
1947	196.6	[illegible]	163.	161.7	165.1	199.6	259.6	283.5	281.9	278.4	270.1	249.4
1948	227.6	[illegible]	[illegible]	198.4	167.9	229.4	283.6	283.2	281.4	274.8	250.7	220.3
1949	168.5	145.1	163.	231.6	252.8	274.5	282.3	282.1	273.7	242.6	205.4	166.1
1950	130.6	177.7	115.	153.2	168.0	181.0	269.1	282.1	281.5	270.2	251.5	236.5
1951	215.5	[illegible]	265.	232.7	283.6	283.5	283.6	279.1	262.1	246.2	235.6	212.6
1952	190.9	218.5	245.	274.4	282.5	280.7	283.6	283.1	279.4	262.4	235.8	216.7
1953	191.0	155.2	176.	196.7	236.6	263.3	283.6	283.5	272.0	243.4	203.5	165.8
1954	106.2	107.5	131.	138.3	158.9	197.9	214.8	244.8	247.6	213.6	167.5	130.1
1955	100.5	107.7	131.	153.6	148.6	185.6	225.6	237.1	226.6	197.2	178.7	186.8
1956	231.9	255.9	256.	251.4	245.4	273.1	283.6	283.0	278.7	254.9	217.2	179.8
1957	168.1	154.7	162.	183.4	190.8	200.3	233.0	251.2	253.1	220.4	176.4	132.3
1958	95.1	77.2	84.	127.2	131.3	154.4	212.1	282.9	277.1	254.9	222.7	186.8
1959	166.6	186.7	282.1	199.7	218.5	222.6	270.9	280.6	258.2	222.2	184.4	148.8
1960	135.1	161.3	223.7	259.4	272.3	277.5	283.6	282.4	280.0	274.2	251.3	245.8
1961	266.6	281.3	253.	233.6	214.0	266.2	283.6	283.3	280.5	267.6	239.5	217.5
1962	179.6	142.7	129.	134.9	139.6	145.5	224.1	244.5	218.9	176.5	134.4	94.6
1963	67.9	65.2	77.	79.0	81.0	89.6	179.4	190.6	186.7	171.6	150.6	116.1
1964	87.1	62.9	77.	59.2	120.3	172.1	223.0	239.0	216.9	181.0	141.4	100.8
1965	62.7	27.5	5.	8.2	24.3	42.0	62.1	96.3	86.5	57.9	30.7	8.9
1966	2.3	-6.2	1.	6.3	10.3	57.4	97.4	121.0	136.5	124.5	93.8	64.8
1967	46.2	47.2	49.	57.1	94.5	95.7	154.4	196.9	198.1	188.0	167.4	144.3
1968	123.7	[illegible]	147.	151.1	[illegible]	141.5	237.5	229.0	263.9	271.6	241.8	205.5
1969	175.7	[illegible]	196.	197.7	[illegible]	[illegible]	250.0	279.4	275.7	256.0	242.8	216.6
1970	[illegible]	[illegible]	194.	[illegible]	[illegible]	211.4	262.2	283.3	272.7	249.4	224.9	197.2
1971	[illegible]	[illegible]	195.7	173.1	185.5	[illegible]	269.8	283.2	269.1	233.1	202.8	182.7
1972	164.7	147.7	176.	232.4	215.1	243.5	279.3	283.2	282.3	279.2	257.5	224.0
1973	191.	231.4	264.	[illegible]	251.9	251.5	283.4	283.4	281.6	277.4	255.9	226.1
1974	207.5	174.2	196.	267.2	282.8	283.5	283.5	283.1	273.3	254.4	236.4	234.1
1975	239.1	[illegible]	272.	262.3	282.3	283.3	283.5	283.2	281.3	266.7	252.9	237.6
1976	257.5	271.6	282.7	281.0	283.5	283.6	283.4	283.2	278.3	271.2	256.2	249.5
1977	262.4	277.7	273.	262.5	265.0	260.6	283.4	282.4	266.9	236.6	206.9	225.2
AVG	171.4	164.6	178.	190.1	195.6	211.9	246.9	259.7	254.3	236.1	211.5	186.3

EXHIBIT IV-3

CONN. WATER RESOURCES DIVISION
PROPORTION AROUND MONTAGUE

* * * * * P H A S E II * * * * *

DELAWARE RIVER DAILY FLOW MODEL
LOWER BASIN RES. STORAGE COMBINED (BG)

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1929	45.[illegible]	45.[illegible]	45.[illegible]	45.8	45.9	45.9	45.9	45.9	45.9	45.8	44.0	43.5
1930	45.[illegible]	45.8	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	41.6	34.4
1931	23.[illegible]	13.7	6.[illegible]	6.1	7.4	13.2	36.6	42.2	45.1	45.6	45.6	44.4
1932	[illegible]	23.9	15.4	21.6	35.1	4[illegible].5	45.3	45.9	45.9	45.8	43.5	34.8
1933	29.[illegible]	41.6	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.8	45.9
1934	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.8	45.8
1935	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1936	45.4	45.8	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.2	43.9
1937	42.7	44.7	45.[illegible]	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1938	45.8	45.9	45.[illegible]	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1939	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.4	44.2	40.5
1940	35.4	[illegible].6	42.	44.0	44.5	45.3	45.9	45.9	45.9	45.9	45.6	45.9
1941	45.	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.8
1942	37.	34.4	34.7	43.6	45.4	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1943	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.5
1944	[illegible]	45.5	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.5	41.9
1945	41.1	4[illegible].2	44.[illegible]	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1946	45.[illegible]	45.9	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1947	45.9	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1948	45.[illegible]	45.[illegible]	45.	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1949	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.7	45.5
1950	45.6	45.7	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1951	45.7	45.9	45.	45.[illegible]	45.9	45.9	45.5	45.9	45.5	45.9	45.9	45.9
1952	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.5	45.9	45.9	45.9
1953	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.4
1954	41.9	43.4	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.3	40.8	40.2
1955	4[illegible]	43.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.0	42.8	45.9
1956	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1957	45.9	45.9	45.[illegible]	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.0	37.5	25.5
1958	16.7	16.6	27.[illegible]	41.2	44.6	45.6	45.9	45.9	45.9	45.9	45.6	44.7
1959	45.6	45.9	45.[illegible]	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.8	45.6	45.8
1960	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1961	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1962	45.7	45.4	45.	45.[illegible]	45.9	45.9	45.9	45.9	45.9	43.0	38.8	35.3
1963	37.[illegible]	4[illegible].7	43.[illegible]	45.5	45.9	45.9	45.9	45.9	45.9	45.4	44.9	36.8
1964	31.4	2[illegible].6	33.[illegible]	4[illegible].7	45.5	45.9	45.9	45.9	45.9	45.5	41.3	31.6
1965	21.7	9.1	4.[illegible]	9.4	19.5	33.5	37.8	41.8	41.7	31.5	17.3	5.0
1966	4.1	4.7	6.	17.2	23.7	36.2	41.5	43.7	45.3	41.1	31.9	22.7
1967	20.2	22.9	31.[illegible]	37.3	41.4	44.5	45.9	45.9	45.9	45.9	45.9	45.9
1968	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.6
1969	45.4	45.7	45.	45.[illegible]	45.[illegible]	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9
1970	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.6	45.1
1971	45.[illegible]	45.[illegible]	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1972	45.[illegible]	45.9	45.	45.[illegible]	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.8
1973	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.[illegible]	45.9	45.9	45.9	45.[illegible]	45.9
1974	45.[illegible]	45.9	45.	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1975	45.[illegible]	45.9	45.	45.[illegible]	45.9	45.9	45.[illegible]	45.9	45.9	45.9	45.9	45.9
1976	45.[illegible]	45.9	45.	45.[illegible]	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1977	45.[illegible]	45.[illegible]	45.	45.[illegible]	45.6	45.9	45.9	45.9	45.9	45.6	45.8	45.3
AVG	41.1	41.[illegible]	41.[illegible]	42.[illegible]	43.7	44.6	45.4	45.7	45.7	45.3	44.2	42.5

EXHIBIT IV-4

CON/ WATER RESOURCES ENGINEERS   * * * * P H A S E II * * * *   DELAWARE RIVER DAILY FLOW MODEL
S P E C I A L R U N   DELAWARE RIVER AT MONTAGUE 01438500

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	13496.6	17391.6	16667.6	5136.2	7150.1	6742.2	14254.9	11875.1	12645.9	10718.4	5827.8	3853.8
1929	2018.6	1762.0	2297.6	2955.8	3240.6	12193.0	18873.7	9867.9	2786.4	2012.8	1839.3	1772.9
1930	2961.2	4585.2	5908.8	5493.8	5443.5	8057.3	5455.9	2945.0	4003.8	2243.3	2002.2	1921.8
1931	1775.6	1772.5	1796.1	1561.6	1959.2	6881.6	9542.6	7953.8	4411.3	6059.4	2229.9	1765.0
1932	1760.5	1838.4	2912.9	6780.6	6204.6	4311.3	11203.0	4863.0	4397.0	2741.7	2022.5	1832.8
1933	4532.[illegible]	9884.5	3122.6	4793.9	3713.3	8085.3	12826.6	3684.6	2443.5	1900.3	7168.1	7239.3
1934	3458.5	3714.2	4210.0	6150.3	2695.7	5940.5	11338.0	3755.1	2325.9	2891.0	2245.7	5166.5
1935	4151.6	5032.8	7191.1	6423.0	3372.5	11154.6	7912.7	6619.9	2926.7	5534.5	2512.0	1933.6
1936	2377.5	8679.4	4704.8	3814.8	2496.6	28735.8	13389.6	3504.6	3132.3	2143.0	2157.9	1855.5
1937	2118.4	3781.2	5241.5	9427.5	7660.0	4669.6	12632.9	7675.1	5250.0	3389.4	3007.4	2693.2
1938	4432.9	4525.1	5322.5	5712.9	8627.7	7379.7	7741.7	4013.6	4103.4	6195.6	6947.0	10371.2
1939	3271.2	4454.0	11310.7	3696.8	9474.6	12870.5	15043.3	3996.7	2302.6	1946.4	1994.1	1826.9
1940	2527.2	3921.0	2893.7	1792.2	1621.3	6335.6	22597.8	6737.5	4766.4	2681.7	2173.0	3524.4
1941	2361.5	5379.7	6521.0	4530.1	4486.2	4587.1	9365.9	2409.4	2375.1	2077.5	2086.5	1779.4
1942	1751.4	1735.4	3065.6	2721.1	2391.8	8950.5	5763.8	7698.3	5633.5	2805.9	3083.1	5412.5
1943	7264.6	7429.3	8541.5	6437.6	6305.4	12826.3	9233.8	14833.6	5838.9	2147.4	1848.2	1767.7
1944	2791.5	5728.4	2404.4	1801.5	2189.0	6924.3	9734.3	3965.2	2416.6	1755.8	1781.2	1926.9
1945	1601.8	2230.3	3936.2	4029.3	3273.1	17406.3	7206.3	8764.0	6752.1	9857.2	5916.5	4974.6
1946	5678.1	9871.6	5932.2	7867.3	3357.2	11868.2	3293.3	9923.6	7026.2	2724.4	2463.9	2167.5
1947	2311.6	1969.2	1841.7	4888.6	4851.5	7378.9	10977.2	13657.4	4963.5	8743.1	4632.1	2221.3
1948	1767.6	5349.3	3221.3	2436.4	4162.6	14860.6	12501.5	8982.4	4991.3	3036.7	2375.4	1811.5
1949	1875.5	2839.6	5783.4	10369.7	7368.5	5329.3	6522.8	6815.8	2555.9	1808.2	1834.1	1781.8
1950	1728.4	2168.9	5235.4	6062.3	4017.6	9319.0	11343.1	6635.6	5685.5	3457.3	2751.4	2251.0
1951	1813.6	5921.7	9296.9	8496.7	12774.2	12710.4	13907.3	3270.1	3142.3	2937.4	2242.7	1833.8
1952	2584.4	8297.3	6631.4	9211.0	7968.9	11130.3	16400.0	9641.2	5570.5	5754.2	2256.9	2745.6
1953	1801.9	4465.8	9755.2	7860.4	7750.8	11011.1	12761.1	10125.1	3020.6	1961.8	1774.6	1803.6
1954	1553.3	2397.4	6600.6	3199.0	6831.4	6904.1	6432.0	7704.5	2449.3	1779.4	1757.3	1839.5
1955	1782.1	6719.8	6261.8	4252.4	3567.3	9524.0	6045.3	2759.1	2311.7	1762.3	13459.5	3171.9
1956	14068.1	9303.3	3540.9	3285.0	4609.5	8791.3	21482.5	8121.6	4365.4	2045.9	1755.9	1975.3
1957	1786.6	2752.9	6149.5	4048.4	3808.2	5550.0	9362.9	3249.7	2111.2	1771.9	1781.8	1773.7
1958	1754.9	1835.8	7808.0	5033.6	3470.7	6867.0	18544.2	8316.0	2269.3	2141.4	1791.6	2031.8
1959	3913.[illegible]	5244.2	3998.0	4904.3	4437.3	6477.0	10281.5	3551.2	1899.8	1864.5	1779.3	1821.7
1960	4259.3	7189.2	7892.4	5892.5	7376.9	3974.8	18434.7	4514.6	5560.0	3018.4	3749.1	7764.[illegible]
1961	3323.4	2562.5	2403.3	1864.3	6915.5	9615.6	15115.9	7394.7	3270.3	1922.5	2215.7	1902.7
1962	1759.7	2112.5	2314.7	5425.3	2412.9	7163.0	11083.6	2663.3	1756.0	1716.2	1747.9	1726.6
1963	1850.2	3712.1	2874.1	2934.0	2747.7	9914.8	6967.6	3534.6	2037.6	1914.0	1992.6	1787.7
1964	1766.3	2191.1	3664.6	5709.4	3345.1	11760.6	7328.5	4035.3	2072.9	1791.4	1724.6	1782.6
1965	1620.4	1522.6	2084.6	2217.4	4843.9	3731.3	5460.9	2231.7	1550.2	1472.4	1574.0	1601.0
1966	1686.3	1749.8	2512.2	2331.2	3148.2	9048.8	3855.6	5539.3	3125.5	1704.8	1585.0	1561.7
1967	1557.3	2093.3	3150.5	4271.3	3577.9	6583.5	10408.2	6659.8	3448.4	2795.6	3317.0	1937.3
1968	2499.9	4623.6	6006.3	2946.7	3877.1	7508.3	4848.7	7373.7	7801.4	3032.6	1882.0	2069.8
1969	1838.6	4987.6	5796.1	4048.1	3308.9	5830.4	9045.4	4348.8	4172.4	4684.4	5414.8	1866.3
1970	1741.2	4730.9	5099.9	3251.1	7382.8	5026.4	16066.5	5494.3	2264.0	2022.1	1836.2	2046.5
1971	3702.9	4667.0	3214.6	3527.1	6108.9	9538.9	11160.0	6901.3	2173.2	1803.9	3263.2	2317.5
1972	2429.9	2382.6	9745.8	5712.9	3830.3	11229.0	14514.5	9362.5	14148.9	6698.8	2330.5	1735.3
1973	1779.8	11152.8	9921.1	8844.1	6867.1	7394.6	12094.4	11917.5	11032.3	7080.6	4137.1	1981.1
1974	1988.8	2321.6	14169.5	8278.6	7949.9	9014.8	12376.9	6591.4	3832.3	2631.9	2572.5	4840.3
1975	3264.2	4531.2	6243.5	8654.1	10750.8	10824.5	8566.9	8157.7	6204.9	3107.3	2343.3	4582.4
1976	6593.1	6725.7	4540.2	9141.6	14551.0	9474.1	7064.6	6101.3	3325.7	3970.1	4089.0	2061.1
1977	6480.1	5364.6	3505.5	2440.8	4761.0	19785.3	12149.4	4908.8	1957.5	1885.7	1662.8	6225.6
AVG	3244.6	4743.6	5516.7	5053.9	5276.7	9190.8	11010.3	6512.9	4200.1	3286.9	2942.8	2812.5

EXHIBIT IV-5

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	22833.6	25778.8	27297.3	10849.9	16178.0	12019.5	23208.6	17924.9	19112.0	24227.0	12020.4	8801.1
1929	3913.1	3333.1	3912.3	6710.4	7836.8	22134.6	27702.6	16857.4	5471.8	3392.3	3243.9	3561.3
1930	6642.8	9296.9	9849.7	10364.4	10774.5	15743.9	12351.3	6552.9	7634.2	3957.5	2897.7	2835.5
1931	2787.5	2980.4	3051.2	3591.8	4702.6	10529.4	14357.3	12382.0	7856.3	9184.3	3614.9	2864.4
1932	2812.3	2752.7	3642.4	9443.6	9546.3	8353.8	18210.2	8224.1	6157.3	3767.4	2770.8	2755.5
1933	7327.1	21925.5	7603.9	8834.4	9775.1	18178.7	26002.6	9744.6	5113.8	3899.2	16591.2	19702.9
1934	7176.4	5939.5	6619.1	12962.2	4957.1	12657.[illegible]	22126.8	10282.1	5880.3	4345.8	3457.5	9683.9
1935	9355.3	8866.4	16810.4	11416.2	8527.6	18864.0	12893.7	9761.4	4897.0	15553.5	4719.6	4598.0
1936	3473.7	17762.4	11915.2	13006.9	6766.8	56497.5	25218.7	7647.4	6675.1	3692.6	3347.6	2930.4
1937	3334.8	4715.2	11063.9	20369.9	15809.6	10556.9	21278.1	14210.6	8119.3	5646.2	6611.0	4431.7
1938	6986.9	11097.1	[illegible]	12898.5	15729.0	13592.8	14187.0	7684.4	8856.1	16119.6	11647.2	[illegible]
1939	7453.7	9905.6	23639.5	8958.8	22126.4	23793.3	26178.3	7889.9	4067.1	3115.1	3037.9	2775.3
1940	3479.6	5207.7	4131.0	3916.4	4216.8	16020.2	43108.0	13813.5	10747.0	5161.0	3514.2	8521.9
1941	4072.6	12129.4	12431.8	9550.0	8634.1	10699.4	17696.3	4548.2	4782.7	4973.8	3912.9	2854.4
1942	2792.7	2954.9	6015.5	6373.0	8116.0	18518.3	11790.7	16631.9	10707.2	5651.5	13071.3	10310.6
1943	14266.9	14200.0	16344.2	15430.1	15624.8	22315.6	14837.8	23025.1	11413.4	4549.9	3126.7	2787.3
1944	5237.3	13332.8	4429.3	5820.3	5917.5	16489.0	19956.5	9172.2	6275.9	3514.0	2882.1	3456.5
1945	2984.0	4130.1	7800.4	7767.2	8113.2	29665.0	13875.6	16722.1	12784.6	23787.0	13133.6	11086.7
1946	15795.5	16460.8	13967.8	16191.3	7001.3	21777.0	7650.4	18105.3	16535.6	7273.1	5181.0	4132.5
1947	5594.1	4133.4	3914.4	10069.8	10098.8	16139.2	20869.1	28526.4	12890.2	18203.6	8410.5	4571.7
1948	3191.9	12772.9	6808.5	5413.0	9562.3	28201.9	24500.5	20424.4	11477.0	6884.7	5521.1	3364.1
1949	3132.5	5256.5	9215.0	26938.1	16401.7	11355.4	14236.9	14459.4	5144.5	3895.7	3217.0	3014.5
1950	2952.7	3798.9	8546.4	10620.0	11485.5	10915.7	18621.7	11809.8	10156.2	6939.7	4258.3	3751.8
1951	2997.5	11950.0	21519.4	16716.8	25997.2	21649.9	28126.5	7458.3	7497.5	7322.4	6973.8	3876.1
1952	4700.0	20642.8	15836.7	21186.2	17371.7	22738.7	34723.2	21190.6	12554.4	11236.0	6164.3	9455.3
1953	3606.5	12298.3	22712.3	19247.5	16559.4	22417.2	25071.4	18534.6	6775.4	3829.7	3103.2	3046.5
1954	3124.9	4569.6	14912.3	6243.2	11326.8	14946.1	11666.4	14491.7	4448.3	2806.4	2856.3	3511.7
1955	2890.0	10977.2	11716.1	9294.2	7961.6	18615.9	11640.5	5762.6	4393.6	2613.9	29114.6	6905.8
1956	26899.5	19589.2	6837.9	5760.3	12069.3	17909.5	31680.3	16785.8	9355.1	7822.3	3904.6	4776.6
1957	4545.6	7473.5	14687.1	8592.6	9302.7	12038.8	23549.5	7234.5	4022.2	2865.7	2776.9	2730.6
1958	2899.4	3610.9	17250.1	12974.0	9576.7	19765.3	35029.9	19341.3	5445.9	4324.5	3405.9	3739.0
1959	7570.4	10454.8	6305.8	9248.0	10039.3	13528.4	10503.1	7715.1	4320.9	3632.4	3778.0	4070.8
1960	7246.6	11567.3	17133.9	14104.7	16892.9	8193.2	33142.1	10592.0	9938.2	5918.5	7336.8	17752.4
1961	7167.4	5610.0	4635.8	4441.8	14377.2	22850.2	26508.9	15049.2	6579.3	4859.5	5175.9	3807.9
1962	2875.0	4718.0	5769.9	11736.3	7607.9	17778.1	20547.8	5570.7	3208.8	2804.9	3125.0	2952.2
1963	3669.5	9764.6	6487.8	5890.4	5479.7	21569.4	12108.7	7306.1	3871.1	3037.0	2940.0	2867.6
1964	2772.5	3915.4	6150.4	12907.1	8374.9	20602.0	16217.9	9912.5	4221.6	3017.5	2756.2	2817.4
1965	2810.3	2856.4	4030.3	4208.9	10969.8	8004.7	9310.9	4952.4	2965.6	2749.2	2770.1	2839.1
1966	3239.7	2996.5	4245.9	4500.5	8390.7	16404.7	7568.0	10454.7	5259.5	2879.6	2748.2	3010.1
1967	3437.4	4102.9	6326.1	9398.7	8315.0	17815.7	17855.9	13973.8	6211.3	5602.5	10242.6	4495.5
1968	4991.8	9386.2	14071.5	6458.9	9227.8	15463.0	10670.1	13841.2	18777.7	6521.5	3270.2	3832.2
1969	3286.5	9151.2	11127.0	6875.3	6566.3	11504.5	17221.7	9220.0	8331.3	10973.7	16240.7	4562.3
1970	3670.2	9118.6	12144.6	6691.7	15551.6	11417.6	33673.0	11397.8	5397.0	4183.1	3752.1	3161.6
1971	8139.9	16195.0	8339.1	7649.5	16664.8	24299.1	18649.9	13095.0	7150.1	3573.4	8557.6	9174.8
1972	7561.2	9776.9	2 122.5	13319.8	1 674.9	25126.5	22887.8	18491.3	33861.1	14810.7	4518.7	3223.6
1973	3369.3	25304.8	24936.1	19846.5	19341.5	15510.5	26395.8	23108.6	18107.7	18484.6	9298.6	5223.0
1974	4502.4	5793.8	31504.2	18301.2	15694.5	19158.9	25731.9	14006.6	7582.4	4603.0	5636.2	11655.0
1975	5 71.0	8326.9	18793.0	18601.1	21607.2	22276.2	17603.6	16203.9	14056.3	14026.2	6433.4	11576.8
1976	15607.4	15382.9	9808.9	20593.0	25484.2	16019.5	13610.6	11443.2	7534.0	7914.2	7497.1	4400.1
1977	16431.4	9692.0	7239.2	3523.3	8309.2	36939.6	25042.3	10016.0	4290.8	3448.9	3261.9	8255.8
AVG	6242.9	9653.7	11523.2	10916.2	11812.8	18593.[illegible]	20511.9	12871.1	8572.2	7075.3	6140.7	5746.0

EXHIBIT IV-6

CDM/ WATER RESOURCES ENGINEERS
S P E C I A L   R U N

* * * * * P H A S E   II * * * * *

DELAWARE RIVER DAILY FLOW MODEL
COMBINED NYC RESERVOIR STORAGE (BG)

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	283.3	283.6	283.5	282.9	282.7	282.5	283.6	283.5	283.4	283.0	281.6	273.9
1929	254.1	229.4	213.9	234.4	199.1	232.6	282.3	283.5	275.0	254.6	222.4	195.0
1930	170.8	164.8	173.9	197.2	198.9	234.1	258.2	254.5	247.8	229.9	198.6	169.4
1931	137.3	104.5	87.2	71.8	56.3	59.3	131.5	180.0	197.2	198.8	199.4	173.3
1932	141.5	113.5	107.9	132.8	172.8	174.5	230.1	253.8	246.1	237.9	210.5	176.3
1933	174.9	231.7	216.9	211.8	209.5	216.6	269.4	281.3	265.1	234.2	209.1	243.3
1934	246.8	243.4	244.6	258.6	254.3	258.9	281.5	281.7	264.4	236.9	212.3	196.1
1935	202.8	204.5	235.5	254.4	258.3	271.4	283.5	282.5	266.8	258.6	246.1	218.0
1936	187.9	199.3	235.4	240.0	233.4	259.4	283.6	279.2	260.3	231.8	196.8	171.9
1937	143.2	151.4	157.0	184.7	220.1	232.5	262.3	283.2	280.4	275.9	255.2	247.7
1938	240.1	259.2	269.2	273.6	283.4	283.1	283.4	280.1	276.5	272.3	281.3	274.4
1939	277.6	273.0	282.7	279.1	276.2	283.5	283.7	278.4	257.2	226.4	192.0	159.0
1940	133.7	134.7	131.9	124.5	108.7	127.5	223.7	282.7	278.5	262.3	233.6	213.2
1941	191.6	182.3	189.5	221.2	213.9	211.3	246.0	256.7	235.7	207.2	180.6	144.4
1942	104.1	78.0	65.5	84.8	91.1	118.8	174.5	193.8	215.9	199.5	175.0	151.3
1943	155.5	169.0	191.4	230.3	231.1	270.7	283.4	283.7	280.6	259.3	228.8	192.5
1944	153.0	158.8	161.4	141.5	127.8	137.6	188.4	216.2	204.6	178.6	143.4	113.6
1945	92.2	74.0	84.7	137.5	108.3	183.4	250.5	273.6	283.0	278.7	276.3	263.7
1946	278.6	283.5	282.0	282.1	274.6	281.7	280.3	277.8	281.6	267.1	244.2	216.2
1947	196.7	180.5	163.2	162.8	185.2	189.9	259.8	283.5	281.9	278.4	270.1	249.4
1948	220.6	229.8	210.9	198.4	187.9	225.4	283.6	283.2	281.4	274.8	250.7	220.2
1949	188.7	165.9	163.2	232.6	252.6	274.2	282.2	283.1	273.7	242.6	205.2	166.0
1950	131.9	108.1	115.5	153.2	168.0	180.9	260.0	263.1	281.3	269.8	251.2	236.2
1951	215.5	197.4	269.1	282.6	283.6	283.4	283.6	279.1	262.1	246.2	235.6	212.6
1952	192.9	219.4	245.8	274.4	282.5	280.7	283.6	263.1	279.4	262.4	239.8	218.7
1953	190.9	159.1	178.8	198.7	236.6	263.2	283.6	283.5	272.0	243.4	203.4	165.6
1954	124.3	107.3	131.9	138.3	158.9	197.9	214.8	244.8	247.6	214.0	169.3	132.5
1955	102.1	109.0	132.7	154.5	149.2	190.2	226.2	237.7	227.2	198.0	181.2	191.4
1956	204.5	253.5	260.9	254.0	247.9	273.9	283.5	283.0	278.7	254.9	217.1	179.7
1957	166.1	154.5	162.8	183.2	190.6	200.1	232.8	251.0	252.8	220.2	176.5	137.0
1958	101.6	75.8	86.0	129.0	133.1	136.2	213.8	283.0	277.0	254.9	222.7	187.1
1959	165.8	186.8	202.2	198.8	218.6	222.7	271.0	280.6	258.2	222.2	184.7	149.2
1960	135.2	161.5	223.9	259.6	272.3	277.3	283.6	282.4	280.0	274.2	251.3	245.8
1961	266.5	261.3	253.1	233.6	214.3	266.5	283.6	283.3	280.5	267.6	239.5	217.5
1962	178.5	143.2	130.2	135.2	139.7	145.6	224.2	244.6	219.5	178.3	137.4	98.5
1963	71.8	67.8	77.8	79.7	81.7	90.3	179.8	190.6	186.8	171.6	150.6	119.5
1964	90.3	70.7	77.7	89.2	120.2	173.0	223.0	239.0	216.9	181.1	142.5	104.4
1965	68.2	37.7	15.3	18.1	34.1	51.9	72.0	106.1	95.8	69.9	46.8	27.5
1966	21.3	12.1	19.7	24.4	28.3	71.4	115.4	139.0	153.1	136.3	105.8	76.1
1967	60.3	54.4	63.3	71.2	99.0	109.7	177.2	204.5	205.3	195.2	174.6	151.5
1968	130.4	135.9	154.6	158.3	156.6	166.5	212.4	233.8	268.8	275.7	245.8	213.8
1969	179.8	165.7	190.9	232.1	208.1	230.6	254.1	282.0	275.7	256.0	242.7	216.3
1970	179.6	174.2	194.6	193.0	210.7	212.5	262.2	283.3	272.7	249.4	224.9	197.7
1971	186.4	192.9	196.0	193.3	190.2	229.8	270.0	283.2	269.1	233.1	202.6	182.5
1972	164.5	149.6	178.8	212.4	215.0	243.5	279.2	283.2	282.3	279.2	257.5	223.9
1973	190.9	201.3	264.0	283.0	281.9	281.8	283.4	283.4	281.6	277.4	255.9	226.1
1974	230.6	174.2	196.3	267.1	282.8	283.5	283.5	283.1	273.3	254.4	236.3	234.1
1975	239.1	238.1	272.5	282.3	282.3	283.3	283.5	283.2	281.3	266.7	252.9	237.5
1976	257.9	278.6	282.5	281.0	283.5	283.6	283.4	283.2	278.3	271.2	256.2	249.4
1977	262.4	277.6	273.6	262.5	265.2	280.6	283.4	282.4	266.9	236.6	209.0	225.4
AVG	173.2	168.6	180.0	191.8	197.2	213.4	248.2	260.7	255.2	237.0	212.7	189.8

EXHIBIT IV-7

CDM/ WATER RESOURCES ENGINEERS • • • • P H A S E II • • • • DELAWARE RIVER DAILY FLOW MODEL
S P E C I A L R U N LOWER BASIN RES. STORAGE COMBINED (BG)

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1929	45.9	45.9	45.8	45.8	45.9	45.9	45.9	45.9	45.9	45.8	43.5	43.0
1930	45.3	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	46.4	31.5
1931	17.6	4.8	-1.4	-4.0	-3.1	2.5	29.5	37.4	41.9	43.5	44.6	42.9
1932	31.7	15.1	5.4	11.7	25.3	33.7	42.6	45.2	45.9	45.8	43.5	32.8
1933	25.6	39.1	44.5	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.9
1934	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.8	45.6
1935	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1936	45.1	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.5	45.2	43.7
1937	42.4	44.7	45.6	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1938	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1939	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.2	43.0	37.9
1940	30.7	33.3	37.9	41.7	43.1	44.2	45.9	45.9	45.9	45.9	45.8	45.9
1941	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.3
1942	34.4	33.0	30.3	41.1	44.3	45.7	45.9	45.9	45.9	45.9	45.9	45.9
1943	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.1
1944	40.1	45.4	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.6	45.4	40.0
1945	38.3	37.1	42.8	45.4	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1946	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1947	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1948	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1949	45.6	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.5	45.1
1950	45.2	45.7	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1951	45.3	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1952	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1953	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.7	44.2
1954	40.9	41.7	45.2	45.9	45.9	45.9	45.9	45.9	45.9	45.1	39.3	37.1
1955	37.6	42.3	44.9	45.9	45.9	45.9	45.9	45.9	45.9	44.7	41.9	45.9
1956	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1957	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	44.7	34.7	20.4
1958	9.0	6.9	19.7	36.3	45.2	44.8	45.9	45.9	45.9	45.9	45.8	44.1
1959	45.4	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.8	45.9
1960	45.6	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1961	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1962	45.5	44.8	45.8	45.9	45.9	45.9	45.9	45.9	45.9	41.3	35.3	31.1
1963	31.6	37.8	41.2	43.2	44.8	45.7	45.9	45.9	45.9	45.3	44.6	36.7
1964	27.1	21.3	29.1	37.4	44.1	45.7	45.9	45.9	45.9	45.5	40.0	27.4
1965	14.6	-.7	-8.3	-4.3	5.7	21.9	30.8	34.8	34.3	21.2	2.7	-12.7
1966	-13.7	-12.8	-8.6	-.3	5.7	23.9	32.5	36.3	39.4	35.3	24.2	13.3
1967	8.2	10.1	18.9	28.0	35.1	39.1	45.4	45.9	45.9	45.9	45.9	45.9
1968	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.0
1969	44.9	45.5	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1970	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.8
1971	45.3	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1972	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1973	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1974	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1975	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1976	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1977	45.9	45.9	45.9	45.6	45.5	45.9	45.9	45.9	45.9	45.6	45.8	45.1
AVG	39.4	39.1	39.8	41.3	42.4	43.6	44.9	45.3	45.4	44.9	43.4	41.3

EXHIBIT IV-8

COM/ WATER RESOURCES ENGINEERS • • • • P H A S E II • • • • DELAWARE RIVER DAILY FLOW MODEL
S P E C I A L R U N DELAWARE RIVER AT MONTAGUE 01438500

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	13496.6	17391.6	16667.6	5196.2	7150.1	6742.2	14254.9	11875.1	12645.9	10718.4	5027.8	3853.6
1929	2018.6	1762.0	2297.6	2955.8	3240.6	12193.0	18873.7	9867.9	2786.4	2012.8	1839.3	1772.9
1930	2961.2	4585.2	5908.8	5493.8	5443.5	8057.3	5455.9	2945.0	4003.8	2243.3	2002.2	1921.8
1931	1775.6	1677.6	1743.6	1563.5	1945.3	6881.6	9542.6	7936.2	4156.4	5976.8	2229.3	1792.0
1932	1810.6	1832.0	2893.6	6769.0	6204.6	4293.0	11207.5	4863.0	4397.0	2743.8	2029.6	1830.3
1933	4933.4	9884.5	3122.6	4796.6	3713.3	8085.5	12695.8	3684.6	2443.5	1900.3	7166.1	7235.3
1934	3458.5	3714.2	4210.0	6150.3	2695.7	5940.5	11338.0	3755.1	2325.9	2891.0	2245.7	5106.5
1935	4151.6	5902.8	7191.1	6423.0	3372.5	11154.6	7912.7	6619.9	2926.7	5534.5	2512.0	1933.6
1936	2377.5	8679.4	4704.8	3814.8	2496.6	28705.8	13389.6	3504.6	3132.3	2143.0	2157.9	1855.5
1937	2118.4	3781.2	5241.5	9427.5	7660.0	4669.6	12632.9	7675.1	5250.0	3389.4	3207.4	2693.2
1938	4432.9	4525.1	5322.5	5712.9	8627.7	7379.7	7741.7	4013.6	4103.4	6199.6	6947.0	10376.2
1939	3271.2	4404.0	11313.7	3656.8	9474.6	12870.5	15043.3	3996.7	2302.6	1946.4	1994.1	1826.9
1940	2527.2	3901.0	2693.7	1699.9	1606.5	6337.3	22538.7	6492.3	4772.0	2681.7	2173.0	3524.4
1941	2361.5	5379.7	6521.0	4500.1	4486.2	4587.1	9365.9	2409.4	2375.1	2077.5	2086.5	1775.4
1942	1749.2	1650.3	3074.9	2721.1	2391.8	6920.2	5755.9	7687.1	5633.5	2805.9	3063.1	5411.7
1943	7264.6	7489.3	8541.5	6437.6	6305.4	12065.1	9233.8	14833.6	5638.9	2147.4	1848.2	1767.7
1944	2791.5	5728.4	2434.4	1863.4	2138.1	6920.5	9730.4	3965.2	2416.5	1735.5	1644.3	1859.8
1945	1666.1	2174.1	3923.5	3965.1	3273.1	17397.6	7208.3	8610.9	6752.1	9857.2	5916.5	4974.6
1946	5678.[illegible]	9871.6	5932.2	7867.3	3357.2	11868.2	3293.3	9923.6	7026.2	2724.4	2463.9	2167.5
1947	2311.8	1969.2	1841.7	4888.6	4851.5	7378.9	10977.2	13657.4	4963.5	8743.1	4632.1	2221.3
1948	1767.6	5349.3	3221.3	2436.4	4062.6	14860.6	12501.5	8982.4	4991.3	3036.7	2375.4	1811.5
1949	1875.5	2809.6	5083.4	10389.7	7368.5	5329.3	6522.8	6015.8	2555.9	1808.2	1834.1	1781.8
1950	1726.4	2134.0	5202.0	6062.3	4017.6	9319.0	11343.1	6606.4	5073.5	3457.3	2751.7	2192.8
1951	1783.1	5935.7	9324.5	8515.8	12774.2	12710.4	13907.3	3270.1	3142.3	2937.4	2242.7	1833.8
1952	2564.4	8297.3	6631.4	9211.0	7968.9	11130.3	16400.0	9641.2	5570.5	5754.2	2256.9	2745.6
1953	1601.9	4465.8	9755.2	7860.4	7750.8	11011.1	12761.1	10125.1	3020.6	1961.8	1774.6	1803.6
1954	1853.1	2353.3	6597.7	3194.7	6824.3	6904.1	6432.0	7704.5	2449.5	1796.2	1753.6	1853.9
1955	1697.6	6695.2	6261.8	4252.1	3560.3	9519.1	6045.3	2756.6	2311.0	1779.7	13462.1	3171.9
1956	14088.1	9303.3	3546.9	3285.8	4609.5	8709.6	21479.1	8121.6	4365.4	2045.9	1755.9	1975.3
1957	1786.6	2752.9	6149.5	4048.9	3808.2	5558.0	9362.9	3249.7	2111.2	1771.9	1781.8	1773.7
1958	1698.2	1800.3	7805.4	5033.6	3468.8	6846.7	18485.5	8006.6	2269.3	2141.4	1791.6	2031.8
1959	3813.0	5244.2	3398.0	4904.3	4437.3	6477.0	10281.5	3551.2	1899.8	1864.5	1779.3	1821.7
1960	4259.3	7189.2	7892.4	5892.5	7376.9	3974.8	18434.7	4514.6	5560.0	3610.4	3749.1	7764.0
1961	3323.4	2562.5	2403.3	1864.3	6915.5	9615.6	15115.9	7394.7	3270.3	1922.5	2215.7	1902.7
1962	1759.7	2112.5	2309.4	5419.4	2401.3	7163.0	11083.6	2663.3	1755.2	1707.2	1656.5	1675.2
1963	1804.2	3712.1	2874.1	2904.0	2718.3	9914.1	6908.5	3458.4	2014.0	1851.5	1036.1	1672.3
1964	1646.6	2146.1	3664.8	5709.4	3297.3	11693.9	7328.5	4031.7	2079.0	1722.8	1674.7	1576.6
1965	1603.2	1476.3	2087.9	2217.9	4843.2	3731.3	5460.9	2216.2	1543.1	1515.2	1526.7	1562.7
1966	1581.4	1748.8	2512.2	2332.4	3143.7	9948.8	3855.6	5539.3	3088.8	1607.6	1511.8	1600.1
1967	1544.0	2085.0	3150.5	4271.3	3577.9	6583.5	10298.4	6556.3	3081.3	2419.7	2946.4	1511.6
1968	2392.3	4593.6	6106.3	2899.8	3795.7	7474.0	4848.7	7373.7	7801.4	2989.0	1896.8	2387.1
1969	1838.7	4986.4	5096.1	4048.1	3300.9	5830.4	9045.4	3957.9	4156.9	4679.4	5414.8	1851.5
1970	1789.1	4702.4	5099.9	3251.1	7382.8	5026.4	15602.8	5494.3	2264.0	2222.1	1838.2	2046.5
1971	3702.9	4667.0	3204.6	3527.1	6008.9	9508.9	11160.0	6901.3	2173.2	1803.9	3263.2	2317.5
1972	2429.9	2362.6	9745.8	5712.9	3830.3	11229.0	14514.5	9362.5	14148.9	6698.8	2330.5	1735.3
1973	1779.8	11152.8	9921.1	8844.1	6867.1	7394.6	12094.4	11917.5	11032.3	7080.6	4137.1	1981.1
1974	1988.8	2321.6	14169.5	8278.6	7949.9	9814.8	12376.9	5591.4	3832.3	2631.9	2572.5	4841.3
1975	3264.2	4531.2	8243.5	8654.1	10750.8	10824.5	8566.9	8157.7	6204.9	3107.3	2343.3	4582.4
1976	6590.1	6720.7	4540.2	9161.8	14551.0	9474.1	7164.6	6101.3	3325.7	3970.1	4089.0	2061.1
1977	8480.1	5064.6	3605.5	2440.8	4061.0	19785.3	12149.4	4908.8	1957.5	1885.7	1862.8	6229.6
AVG	3234.2	4732.7	5514.9	5249.5	5271.3	9178.2	10992.5	6485.8	4186.0	3273.2	2924.7	28[illegible]1.9

EXHIBIT IV-9

CDM/ WATER RESOURCES ENGINEERS
S P E C I A L R U N

* * * * P H A S E II * * * *

DELAWARE RIVER DAILY FLOW MODEL
DELAWARE RIVER AT TRENTON 01463500

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	22833.8	25778.8	27297.3	10849.9	16178.0	12019.5	23208.6	17924.9	19112.0	24227.0	12020.4	8831.1
1929	3913.1	3333.1	3912.3	6710.4	7836.8	22134.6	27702.6	16857.4	5471.8	3392.3	3243.9	3561.3
1930	6642.8	9206.9	9849.7	10364.4	10774.5	15743.9	12351.3	6552.9	7634.2	3957.5	2897.7	2835.5
1931	2787.5	2947.4	3062.4	3600.7	4680.7	10529.4	14295.6	12378.0	7639.8	9082.8	3612.8	2900.3
1932	2753.1	2752.5	3628.1	9436.1	9546.3	8354.3	18210.1	8233.5	6157.4	3767.4	2772.3	2794.8
1933	7317.7	21924.6	7586.8	8837.1	9775.1	18178.7	25871.9	9744.6	5113.8	3899.2	16591.2	19792.9
1934	7176.4	5939.5	6619.1	12962.2	4957.1	12657.0	22126.8	10282.1	5880.3	4345.8	3457.5	9682.9
1935	9395.3	8866.4	16810.4	11416.2	8527.6	18864.5	12693.7	9761.4	4897.0	15559.5	4719.6	4556.3
1936	3473.7	17782.4	11915.2	13006.9	6768.8	56497.5	25218.7	7647.4	6675.1	3692.6	3347.6	2936.4
1937	3334.8	4715.2	11063.9	20369.9	15809.6	10556.9	21278.1	14210.6	8119.3	5646.2	6611.0	4431.7
1938	9986.9	11397.1	13525.1	12898.5	15729.0	13592.8	14187.0	7684.4	8856.1	16119.6	11647.2	16930.6
1939	7453.7	9955.6	23639.5	8958.8	22126.4	23793.3	26178.3	7889.9	4767.1	3115.1	3037.9	2775.3
1940	3409.6	5207.7	4131.9	3832.6	4196.8	16017.4	43371.4	13556.3	10745.6	5161.0	3514.2	8521.9
1941	4372.6	12129.4	12431.8	9550.0	8634.1	10699.4	17696.3	4548.2	4782.7	4973.8	2912.9	2834.4
1942	2777.4	2941.3	6011.9	6340.0	8105.6	18406.0	11764.9	16622.7	10707.2	5651.5	13071.3	10395.8
1943	14268.0	14200.0	16344.2	15430.1	15624.8	21554.4	14937.8	23029.1	11413.4	4549.9	3128.7	2767.3
1944	5237.3	13332.8	4429.3	5872.3	5866.6	16489.2	19953.6	9172.2	6275.9	3495.9	2829.3	3405.4
1945	2847.7	4125.3	7627.7	7698.7	8066.5	29620.3	13875.6	16368.9	12784.6	23787.0	13133.8	11086.7
1946	10795.5	16460.8	13967.8	16191.3	7001.3	21777.0	7650.4	18105.3	16535.6	7273.1	5181.0	4132.5
1947	5094.0	4133.4	3914.4	10069.8	10098.8	16139.2	20869.1	28526.4	12890.2	18203.6	6410.5	4571.7
1948	3191.9	12772.9	6808.5	5413.0	9562.3	28281.9	24500.5	20424.4	11477.0	6884.7	5521.1	3364.1
1949	3132.5	5256.5	9215.0	26938.1	16401.7	11355.4	14236.9	14459.4	5144.5	3895.7	3217.0	3014.5
1950	2952.7	3764.3	8515.9	10629.0	11485.5	18915.7	18621.7	11791.1	10133.2	6909.7	4258.6	3756.3
1951	2969.9	11945.8	21547.1	16735.9	25997.2	21649.9	28126.5	7458.3	7497.5	7322.4	6073.8	3876.1
1952	4700.0	20642.8	15836.7	21186.2	17371.7	22738.7	34723.2	21190.6	12554.4	11236.0	6164.3	9459.3
1953	3806.5	12298.3	22712.3	19247.5	16559.4	22417.2	25971.4	18534.6	6775.4	3829.7	3103.2	3546.5
1954	3125.9	4524.3	14910.4	6238.9	11320.9	14946.1	11666.4	14491.7	4448.3	2839.4	2861.7	3527.4
1955	2875.5	10889.8	11715.8	9292.5	7962.3	18607.8	11640.5	5759.8	4392.6	2829.5	29119.7	6905.8
1956	26899.5	19589.2	6837.0	5760.3	12069.3	17827.8	31676.9	16765.8	9055.1	7822.3	3904.6	4776.6
1957	4545.6	7473.5	14687.1	8592.6	9302.7	12938.8	23549.5	7234.5	4022.2	2865.7	2776.9	2730.6
1958	2652.0	3597.8	17219.5	12974.0	9574.8	19759.0	34995.7	18999.1	5445.9	4324.5	3405.0	3735.0
1959	7570.4	10454.8	8305.8	9248.0	10039.3	13528.4	18503.1	7715.1	4320.9	3632.4	3778.0	4070.8
1960	7246.6	11567.3	17133.9	14104.7	16892.9	8193.2	33142.1	10592.0	9938.2	5918.5	7336.8	17752.4
1961	7 67.4	5610.0	4635.8	4441.8	14377.2	22856.2	26508.9	15049.2	6579.3	4859.5	5175.9	3807.9
1962	2875.0	4718.0	5769.2	11725.8	7596.2	17778.1	20547.8	5570.7	3216.2	2780.2	3092.7	2943.1
1963	3626.9	9724.3	6593.8	5890.4	5451.8	21533.6	12066.6	7252.4	3851.4	2987.9	2899.1	2825.9
1964	2789.1	3942.0	6157.2	12663.5	6338.7	20412.6	16217.9	9958.9	4227.9	2985.1	2741.1	2805.7
1965	2762.4	2922.5	4001.7	4208.9	10969.7	8004.7	9134.7	4948.1	2971.5	2739.7	2779.2	2842.4
1966	3210.6	3502.9	4245.9	4501.7	8386.1	16292.0	7568.0	10454.7	5259.0	2914.8	2703.3	3043.9
1967	3427.9	4195.1	6326.1	9300.9	8273.7	17815.7	17763.8	13803.1	5922.2	5274.6	10002.6	4392.0
1968	4915.3	9958.8	14071.5	6434.9	9167.5	15430.1	10670.1	13841.2	18777.7	6477.7	3286.5	3842.8
1969	3287.2	9154.7	11127.6	6875.3	6566.3	11504.5	17221.7	8834.1	8310.7	10968.7	16240.7	4549.0
1970	3703.8	9127.4	12144.6	6691.7	18551.6	11417.6	33209.4	11397.8	5397.0	4183.1	3752.1	3161.6
1971	6139.9	16195.0	8339.1	7649.5	16664.8	24299.1	18649.9	13095.0	7150.1	3573.4	8557.6	9174.8
1972	7561.2	9776.9	20122.5	13319.8	19674.9	25126.5	22887.8	18491.3	33861.1	14810.7	4518.7	3223.6
1973	3369.3	25304.8	24936.1	19846.5	19341.5	15510.5	26395.8	23108.6	18107.7	18484.6	9298.6	5233.0
1974	4502.6	5790.8	31504.2	18301.2	15694.5	19158.9	25731.9	14006.6	7582.4	4603.0	5638.2	11655.0
1975	8671.0	8326.9	18793.0	18601.1	21607.2	22276.2	17603.6	16203.9	14056.3	14026.2	6433.4	11576.8
1976	15607.4	15382.9	9808.9	20593.8	25484.2	16019.5	13610.6	11443.2	7534.0	7914.2	7497.1	4400.1
1977	16431.4	9692.0	7239.2	3523.3	8309.2	38939.6	25942.3	10016.0	4290.8	3440.9	3261.9	8259.8
AVG	6235.7	9649.6	11518.3	10904.9	11806.0	18567.0	20490.9	12844.7	8561.2	7064.1	6130.8	5740.1

EXHIBIT IV-10

COM/ WATER RESOURCES ENGINEERS
S P E C I A L R U N

• • • • P H A S E II • • • •

DELAWARE RIVER DAILY FLOW MODEL
COMBINED NYC RESERVOIR STORAGE (BG)

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	283.3	283.6	283.5	282.9	282.7	282.5	283.6	283.5	283.4	283.0	281.6	272.9
1929	254.1	229.4	213.9	204.4	199.1	232.6	282.3	283.5	275.0	254.6	222.4	185.0
1930	170.8	164.8	173.9	197.2	198.9	234.1	258.2	254.5	247.8	229.9	198.6	169.4
1931	137.3	104.9	88.2	70.3	51.2	50.7	119.7	167.8	189.9	196.8	197.5	171.1
1932	138.7	110.7	104.9	128.7	169.0	170.9	227.8	251.4	243.8	235.5	208.2	175.8
1933	172.4	199.2	214.4	209.3	206.9	214.0	267.9	281.3	265.1	234.2	209.1	243.3
1934	246.8	243.4	244.6	258.6	254.3	258.9	281.5	281.7	264.4	236.9	212.3	196.1
1935	202.8	204.5	235.5	254.4	258.3	271.4	283.5	282.5	266.8	258.6	246.1	218.0
1936	187.9	199.3	235.4	240.0	233.4	259.4	283.6	279.2	260.3	231.8	198.8	171.9
1937	143.2	151.4	157.0	134.7	220.1	232.5	262.3	283.2	280.4	275.9	255.2	247.7
1938	240.1	259.2	269.2	273.6	283.4	283.1	283.4	280.1	276.5	272.3	281.3	274.4
1939	277.6	273.0	282.7	279.1	276.2	283.5	283.7	278.4	257.2	226.4	192.0	155.0
1940	133.7	134.7	131.9	124.6	106.2	103.4	217.9	281.0	278.5	262.3	233.6	213.2
1941	191.6	182.3	189.5	221.2	213.9	211.3	246.0	256.7	235.7	207.2	160.6	144.4
1942	133.9	77.4	62.9	78.6	81.3	165.9	160.4	178.8	200.6	164.3	159.7	136.1
1943	141.3	153.7	176.1	215.0	215.8	261.5	283.4	283.7	280.6	259.3	228.8	192.5
1944	153.[illegible]	158.8	161.4	141.5	127.4	136.4	186.2	214.1	202.4	176.9	143.8	114.5
1945	94.1	77.0	86.5	107.8	106.7	180.2	247.4	271.6	283.0	278.7	278.3	263.7
1946	276.6	283.5	282.9	282.1	274.6	281.7	280.3	277.8	281.6	267.1	244.2	216.2
1947	196.7	180.5	163.2	162.8	185.2	189.9	259.8	263.5	281.9	278.4	270.1	249.4
1948	220.6	209.8	210.9	198.4	187.9	225.4	283.6	283.2	281.4	274.8	250.7	220.2
1949	198.7	165.9	163.2	232.6	252.6	274.2	282.2	283.1	273.7	242.6	205.2	166.0
1950	131.7	158.0	114.8	152.6	167.4	180.4	259.5	283.1	281.5	270.1	251.5	236.4
1951	216.1	198.4	269.7	282.7	283.6	283.4	283.6	279.1	262.1	246.2	235.6	212.6
1952	192.9	218.4	245.8	274.4	282.5	280.7	283.6	283.1	279.4	262.4	239.8	218.7
1953	190.9	159.1	178.8	198.7	236.6	263.2	283.6	283.5	272.0	243.4	203.4	165.6
1954	126.3	107.1	131.3	137.5	157.7	196.7	213.6	243.6	246.4	212.6	167.5	131.8
1955	103.9	107.8	131.5	153.3	147.8	188.9	224.9	236.3	225.9	196.5	179.5	169.7
1956	202.8	251.8	259.2	252.3	246.2	273.2	283.5	283.0	278.7	254.9	217.1	175.7
1957	168.1	154.5	162.8	183.2	190.6	200.1	232.8	251.0	252.8	220.2	176.5	137.0
1958	131.7	75.8	84.1	125.1	127.7	129.4	206.7	282.2	277.0	254.9	222.7	187.1
1959	166.9	186.8	202.2	198.8	218.6	222.7	271.0	280.6	256.2	222.2	184.7	145.2
1960	135.2	161.5	223.9	259.6	272.3	277.3	283.6	282.4	280.0	274.2	251.3	249.8
1961	265.8	261.3	253.1	233.6	214.3	266.5	283.6	283.3	280.5	267.6	239.5	217.5
1962	178.5	143.2	130.2	135.0	138.6	143.2	220.9	241.4	216.2	175.4	134.8	96.2
1963	69.2	62.5	71.6	70.6	69.1	74.1	163.3	178.4	175.9	160.6	143.4	115.4
1964	87.2	69.0	75.7	84.1	113.1	165.4	215.3	231.3	209.2	175.4	138.6	101.8
1965	67.4	34.5	8.4	7.3	19.8	34.0	50.4	80.9	67.3	36.2	9.7	-12.3
1966	-21.8	-34.5	-30.5	-29.6	-29.2	10.4	50.7	70.6	82.5	67.6	35.5	5.7
1967	-16.6	-26.2	-21.0	-16.8	7.5	14.7	81.8	117.7	130.8	135.5	127.6	113.8
1968	99.4	110.1	129.2	133.9	137.8	149.4	195.5	216.9	251.9	259.6	229.5	197.5
1969	163.2	149.0	174.3	185.4	191.5	184.0	237.5	267.9	267.2	247.5	234.3	236.0
1970	171.3	165.2	185.6	184.0	201.7	203.6	256.4	283.3	272.7	249.4	224.9	197.7
1971	186.4	192.9	196.0	193.3	190.2	229.8	270.0	283.2	269.1	233.1	202.6	182.5
1972	164.5	149.6	178.8	212.4	215.0	243.5	279.2	283.2	282.3	279.2	257.5	223.9
1973	190.9	201.3	264.0	283.0	281.9	281.8	283.4	283.4	281.6	277.4	255.9	228.1
1974	200.6	174.2	196.2	267.1	282.8	283.5	283.5	283.1	273.3	254.4	236.3	234.1
1975	239.1	239.1	272.5	272.3	282.3	283.3	283.5	283.2	281.3	266.7	252.9	237.5
1976	257.8	276.6	282.5	281.0	283.5	283.6	283.4	283.2	278.3	271.2	256.2	245.4
1977	242.4	277.6	273.6	262.5	265.2	280.6	283.4	282.4	266.9	236.6	209.0	225.4
AVG	169.1	164.5	175.5	186.7	191.7	207.4	242.3	255.2	250.2	232.4	208.4	185.7

EXHIBIT IV-11

CDM/ WATER RESOURCES ENGINEERS
S P E C I A L R U N

* * * * P H A S E II * * * *

DELAWARE RIVER DAILY FLOW MODEL
LOWER BASIN RES. STORAGE COMBINED (BC)

AVERAGE MONTHLY VALUES

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1928	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1929	45.9	45.9	45.8	45.8	45.9	45.9	45.9	45.9	45.9	45.8	43.5	43.0
1930	45.3	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	40.4	31.5
1931	17.6	4.3	-3.8	-7.4	-6.4	-.6	26.9	35.8	40.2	42.2	43.6	42.1
1932	31.4	15.7	6.1	12.2	25.8	34.2	42.8	45.4	45.9	45.8	43.6	32.9
1933	25.5	38.8	44.3	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.9
1934	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.6	45.8
1935	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1936	45.1	45.6	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.2	43.7
1937	42.4	44.7	45.6	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1938	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1939	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.2	43.0	37.9
1940	30.7	33.3	37.0	41.6	43.1	44.2	45.9	45.9	45.9	45.9	45.8	45.9
1941	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.3
1942	34.4	29.2	28.8	40.2	43.6	45.5	45.9	45.9	45.9	45.9	45.9	45.9
1943	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.1
1944	40.1	45.4	45.5	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.7	37.8
1945	34.4	30.9	37.6	43.4	44.4	45.8	45.9	45.9	45.9	45.9	45.9	45.9
1946	45.5	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1947	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1948	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1949	45.8	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.5	45.1
1950	45.2	45.7	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8
1951	45.4	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1952	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1953	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.7	44.2
1954	40.9	41.7	45.2	45.9	45.9	45.9	45.9	45.9	45.9	45.1	39.6	37.4
1955	37.3	41.7	44.9	45.9	45.9	45.9	45.9	45.9	45.9	44.6	41.7	45.9
1956	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1957	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	44.7	34.7	20.4
1958	8.8	6.0	18.9	35.8	39.7	44.4	45.9	45.9	45.9	45.9	45.8	44.1
1959	45.4	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	45.8	45.9
1960	45.8	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.5	45.9
1961	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1962	45.5	44.8	45.8	45.9	45.9	45.9	45.9	45.9	45.9	41.5	34.9	29.4
1963	29.4	36.2	39.9	41.9	43.8	45.3	45.9	45.9	45.8	44.7	43.0	33.1
1964	21.2	12.4	19.6	29.5	39.9	44.3	45.9	45.9	45.9	45.5	39.7	24.9
1965	8.7	-8.4	-16.0	-11.8	-1.7	14.4	25.9	30.7	30.1	18.2	-.5	-16.3
1966	-18.1	-17.3	-13.1	-4.8	1.2	20.2	30.2	34.0	37.1	31.7	19.3	7.3
1967	2.6	4.6	13.4	22.7	32.3	36.3	43.7	45.7	45.9	45.9	45.9	45.9
1968	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.9
1969	44.7	45.6	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1970	45.6	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.8	44.6
1971	45.3	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1972	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1973	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1974	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1975	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1976	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9	45.9
1977	45.9	45.9	45.9	45.8	45.5	45.9	45.9	45.9	45.9	45.8	45.8	45.1
AVG	38.0	38.3	39.1	40.6	41.9	43.2	44.7	45.1	45.2	44.7	43.2	40.9

EXHIBIT IV-12

STATISTICAL ANALYSIS

As part of the total basin modeling process, two additional combinations were run for the entire 50 years. The two extreme conditions were chosen: Combination One (Beltzville only) and Combination 17 (all reservoirs on line). Statistics were generated for each of these runs as well as the Base Run. Appendix C contains the results from the Base Run described in Chapter II. Appendix D and E contain Combination One and 17, respectively. For each of the 44 key locations, duration tables and curves are produced. Table C-1, D-1, and E-1 contain these tables for the Base Run, Combination One and Combination 17, respectively. Figures C-1 through C-44, D-1 through D-44 and E-1 through E-44 are the duration curves for the respective runs.

For each of the 44 key locations Log-Pearson low flow frequency tables are produced for periods of 1, 3, 7, 14, 30, 60, 90, 120, 183 and 365 consecutive days. Tables C-2.1 through C-2.44 give the results of the Base Run in Appendix C. Tables D-2.1 through D-2.44 show the results of Combination One. Finally, Tables E-2.1 through E-2.44 give the corresponding results of Combination 17. Eighteen stations listed in Table IV-3, chosen from the 44 key locations, have low flow frequency curves for the 7-day and 120-day consecutive day portion of the tables. They are Figures C-45 through C-62 for the Base Run, Figures D-45 through D-62 for Combination One and Figures E-45 through E-62 for Combination 17.

Many of the stations that are downstream from a reservoir have irregular statistics. The Log-Pearson method used cannot accurately account for basic conservation releases. It tries to fit a consistent statistical line through the data. Because of this, the minimum statistical flow is always less than the basic conservation release. This is true for Neversink, Pepacton and Cannonsville as well as the lower basin reservoirs. The low flow frequency tables have been adjusted to show the basic conservation release, not the calculated flow value. Also, as the number of consecutive days increases, so do the maximum flow values. However, directly downstream of a reservoir, the minimum flow will not change as rapidly, if at all.

TABLE IV-3

KEY LOCATIONS FOR LOW FLOW
FREQUENCY CURVES

Location	USGS Station
East Branch Delaware River at Downsville, NY	01417000
West Branch Delaware River at Stilesville, NY	01425000
West Branch Delaware River at Hale Eddy, NY	01426500
Delaware River near Callicoon, NY	01427405
Delaware River near Barryville, NY	01428500
Lackawaxen River at Hawley, PA	01431500
Delaware River at Port Jervis, NY	01434000
Neversink River at Neversink, NY	01436000
Delaware River at Montague, NJ	01438500
Pohopoco Creek at Beltzville Damsite, PA.	01449800
Lehigh River at Bethlehem, PA	01453000
Tohickon Creek at Pipersville, PA	01459500
Delaware River at Trenton, NJ	01463500
Tulpehocken Creek at Blue Marsh Damsite, PA.	01470960
Schuylkill River at Reading, PA	01741500
Schuylkill River at Philadelphia	01474500
Delaware River below Mouth of Schuylkill	None
Delaware River at Delaware Memorial Bridge	None

This causes the frequency curve for, say, the 120 day period to actually fall below or cross the frequency curve for the 90 day period. Whenever these inconsistencies occur, the flows are plotted against duration on log-log paper for the particular probability. Adjustments are made so that low flow always increases with duration. Therefore, as in Phase I, these tables were adjusted to smooth out the curves. In such cases, the adjusted values have been designated in the appendices by asterisks and called "Recalculated".

A few of the stations at the smaller streams' headwaters actually have a few values of zero flow. Because the statistical analysis uses the Log-Pearson method, these zero values cannot be used to determine the probabilities and corresponding flows. Instead, the A969 program uses all non-negative flow values to determine the flow values and then assigns an adjusted probability which assumes there were 50 values used instead of just the non-negative flow values. To arrive at the required probabilities, the flows are plotted versus the adjusted probabilities. The required probabilities are then picked off the graph. These cases are designated in the Appendices as being "Calculated from the adjusted probability".

The final statistical irregularity involves Riegelsville. Because of some negative inflow values, Riegelsville has flow values which are less than its upstream node, Belvidere. The Log-Pearson statistical method calculated frequencies that do not consistently increase from Belvidere to Riegelsville to Trenton. The frequencies for Riegelsville have therefore been adjusted based on a drainage area ratio and the flows at Belvidere and Trenton, whose frequencies are not adjusted.

The differences in the durations and low flow frequencies between the three runs arise from the various reservoirs being put on line to help supplement Trenton's flow. The Base Run is identical to Combination One except where Beltzville is introduced. Comparing the duration tables from Appendix C and D, Base Run and Combination One respectively, Pohopoco Creek below the Beltzville damsite shows that the low flows have been increased from the Base Run by the conservation release in Combination One. The high flows in the duration curve have been reduced marginally in Combination One, accounting for the refilling of the reservoir. This change in the flow characteristics then affects everything further downstream on the Lehigh

River as well as the mainstem of the Delaware River. Of particular concern is Trenton. While the higher flows of the duration curve are calculated to be the same as the basin run, the lower flows have been augmented by 100 cfs. This augmentation is due to the additional reservoir releases needed to maintain a flow objective at Trenton. A Trenton flow objective was not used in the Base Run. Similar characteristics to the duration curves can be found in the low flow frequency tables of Trenton and Beltzville for the two runs.

Combination 17 with all the reservoirs on line affects the downstream characteristics differently for each of the reservoirs. Using the duration curves of Combination 17 with the Base Run results, Appendix E and Appendix C respectively, comparisions of the reservoirs affects can be made. Beltzville and Nockamixon react the same way: increasing low flows and decreasing high flows. The other three reservoirs, Prompton, FE Walter and Hackettstown, react just the opposite: high flows increase while low flows remain approximately the same. The larger high flows in the duration tables are due to the releases being made for the Trenton objective by a single reservoir each day, raising the number of high flows considerably.

Because Prompton Reservoir is located in the Upper Basin, Montague's flow will also be altered. First of all, the duration curve below Prompton is changed by the reservoir's operations. The low flows are approximately equal in each case. The high flows have been increased by the releases necessary to maintain Trenton's flow. Moving down the basin to Montague, the low flow frequencies have reflected the new characteristics due to the reservoir operation. All of the flows increase from the Base Run to Combination 17. However, because of the usage of flow classes rather than individual flow values for the calculation of the duration curve, the number of flows in each class remained nearly the same. Therefore the resulting duration curves are identical.

Trenton's flows are also of particular interest. The duration curve of Combination 17 shows the higher flows have decreased and the lower flows have increased from the Base Run. Because of the maintenance of the Trenton flow objective, the lower flows seen in the Base Run are supplemented by

releases from the reservoirs. The higher flows in the Base Run are reduced as more and more reservoirs are put on line. The natural high flows are retained in storage by the reservoirs to replace the water used to augment Trenton's flow. The low flow frequencies of each run have similar characteristics as the duration curves: the lower flows are increased and the higher flows are decreased in Combination 17 compared to the results of the Base Run.

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